Problem Assessment for the Columbia/Snake River Temperature TMDL

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Introduction

Under Section 303(d) of the Clean Water Act, states must identify waters for which effluent limitations, as required by Section 301, are not sufficient to implement established water quality standards. EPA, Oregon and Washington have identified portions of the main stem of the Columbia River from the International Border (Columbia River Mile 745.0) to the mouth at Astoria, Oregon, and the Snake River from its confluence with the Salmon River at river mile 188 to its confluence with the Columbia River as water quality limited for temperature pursuant to Section 303(d) of the Clean Water Act. Section 303(d) also requires the development of a Total Maximum Daily Load (TMDL) for water bodies included on the 303(d) list. The scope of this Problem Assessment is water temperature in the main stem segments of the Columbia River from the Canadian Border to the Pacific Ocean and the Snake River from its confluence with the Salmon River to its confluence with the Columbia River. This information will be utilized as the framework for the subsequent TMDL.

This Problem Assessment briefly describes the Columbia Basin: geography, climate, hydrology, human development, salmon stocks and Indian Tribes. This is followed by an evaluation of water temperature problems in the Columbia and Snake Rivers, utilizing existing data and the results of temperature modeling. Finally, the effects of elevated temperatures on salmon resources are evaluated.

Temperature Assessment

The water quality standards applicable to most of the river system under consideration in this TMDL restrict temperature increases over specified temperature criteria due to human activities. For example, the Washington standard for the lower Columbia River is:

> *"Temperature shall not exceed 20 C due to human activities. When natural conditions exceed 20 C no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3 C…"*

Evaluation of existing water temperature against this standard requires knowledge or estimates of natural water temperature before the river was impounded.

This temperature assessment relies on existing temperature data and mathematical modeling of the temperature to describe the existing temperature regime of the impounded river and the natural temperature regime of the un-impounded or free flowing river. Both the temperature observations and the temperature simulations provide estimates of water temperature. Since there are information gaps and uncertainties associated with both the observations and the simulations both are used to gain an understanding of the free flowing and impounded temperature regimes and the relative importance of dams, point sources and tributaries in altering the natural regime of the rivers.

There is a considerable record of temperature data from the Columbia and Snake Rivers. McKenzie and Laenen (1998) assembled temperature data from 84 stations along the two rivers within the study area of this TMDL. However, the extensive data base from along the rivers must be used with caution. Little, if any of the data were collected with the express objective of evaluating temperature in the river. Few of the sampling sites have quality assurance objectives or followed quality control plans. Temperature measured at the same time at one dam can vary quite a bit depending on whether it was measured in the fore bay, the tail race or the scroll case. In using these data it is important to compare like stations along the river (e.g. scroll case to scroll case, fore bay to fore bay) and to use long records or repetitive examples when drawing general conclusions about temperature trends.

The temperature model was developed to augment the understanding of temperature in the river derived from analysis of the data record. There is a good deal of information available for development of the temperature model. For example there are 30 years of continuous weather, flow and water temperature data. However, there are also modeling challenges that cause uncertainty in the modeling results. For example there is little information on temperature in the free flowing river to compare with simulated temperatures. Therefore, the problem assessment relies heavily on both data analysis and modeling analysis.

The analysis in the Problem Assessment provides the following information about the natural and existing temperature regimes of the river:

- The temperatures of the Columbia and Snake rivers frequently exceed state and tribal water quality criteria for temperature during the summer months throughout the area covered by this TMDL.
- The water temperatures of the rivers before construction of the dams could get quite warm, at times probably exceeding the 20 °C temperature criteria of Oregon and Washington on the lower Columbia River.
- However, these warm temperatures were much less frequent without the dams in place. Temperature observations show that the frequency of exceedance at Bonneville Dam of 20 °C increased from about 3% when Bonneville was the only dam on the lower river to 13% with all the dams in place.
- The dams appear to be the major cause of warming of the temperature regimes of the rivers. Model simulations using the existing temperatures of tributaries and holding tributary temperatures to 16 °C revealed little difference in the frequency of excursion of 20 °C.
- Global warming or climate change may play a small role in warming the temperature regime of the Columbia River to date. The Frazer River, with no dams, shows an increasing trend in average summer time temperature of 0.012 °C/year since 1941, 0.022 °C/year since 1953.
- The average water temperatures of the free flowing river exhibited greater diurnal fluctuations than the impounded river.
- The free flowing river average water temperature fluctuated in response to meteorology more than the impounded river. Cooling weather patterns tended to cool the free flowing river but have little effect on the average temperature of the impounded river.
- The free flowing river water temperatures cooled more quickly in the late summer and fall.
- Alluvial flood plains scattered along the rivers moderated water temperatures, at least locally, and provided cool water refugia along the length of the rivers.
- The existing river can experience temperature gradients in the reservoirs in which the shallow waters are warmer.
- Fish ladders, which provide the only route of passage for adult salmon around the dams, can become warmer than the surrounding river water.

1.0 INTRODUCTION AND SCOPE OF THE PROBLEM ASSESSMENT

The objective of the Clean Water Act (as amended by the Water Quality Act of 1987, Public Law 100-4) is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. Each state has developed standards for water quality that are used to judge how well the objectives of the Clean Water Act are being achieved. The water quality standards consist of the designated beneficial uses of the water and the water quality criteria necessary for achieving and maintaining the beneficial uses.

Under Section 303(d) of the Clean Water Act, states must identify waters for which effluent limitations, as required by Section 301, are not sufficient to implement established water quality standards. EPA, Oregon and Washington have identified portions of the main stem of the Columbia River from the International Border (Columbia River Mile 745.0) to the mouth at Astoria, Oregon, and the Snake River from its confluence with the Salmon River at river mile 188 to its confluence with the Columbia River as water quality limited for temperature pursuant to Section 303(d) of the Clean Water Act. This designation arises from an analysis of data (Smith, 2001; Washington DOE, 1998; Oregon DEQ, 1998) showing these waters do not meet water quality standards during all or part of the year. Table 1-1 lists the reaches of the Columbia and Snake Rivers in the study area that have been included by EPA and the States on the 303(d) list for temperature and require a TMDL for temperature.

Table 1-1. Segments of the Columbia and Snake Rivers listed for Temperature in the Study Area

State	Water Body Name	River Mile	Parameter	Action Needed
ID*	Snake River	139.1 -188.0	Temperature	TMDL
OR	Snake River	176.1-188.0	Temperature	TMDL
OR	Columbia River	0.0 – 309.3	Temperature	TMDL
WA	Columbia River	19 sites	Temperature	TMDL
WA	Snake River	8 sites	Temperature	TMDL

* Listed by EPA 2001

These same reaches of the Columbia and Snake Rivers, depicted in Figure 1-1, encompass most of the action area addressed by the Federal Columbia River Power System (FCRPS) Biological Opinion for Salmon under the Endangered Species Act (ESA) (NMFS, 2000). That Biological Opinion addresses the effects of the FCRPS on 12 salmonid species listed pursuant to the ESA as threatened or endangered. It also addresses the effects of degraded habitat on the 12 listed species and identifies water temperature as an important factor that "affects salmonid metabolism, growth rate and disease resistance, as well as the timing of adult migrations, fry emergence, and smoltification." (NMFS, 2000).

The Biological Opinion states that the effect of water quality [water temperature and total dissolved gas (TDG)] on Federally listed anadromous fish in the basin requires that water quality and ESA listings be addressed in a coordinated manner. "Therefore, the Environmental Protection Agency (EPA), the National Marine Fisheries Service (NMFS), the U.S. Fish and Wildlife Service (USFWS), and the Federal Action Agencies (U.S. Army Corps of Engineers [Corps]; Bureau of Reclamation [BOR]; and Bonneville Power Administration [BPA]) are undertaking efforts to conserve listed species under the ESA and create a nexus of water

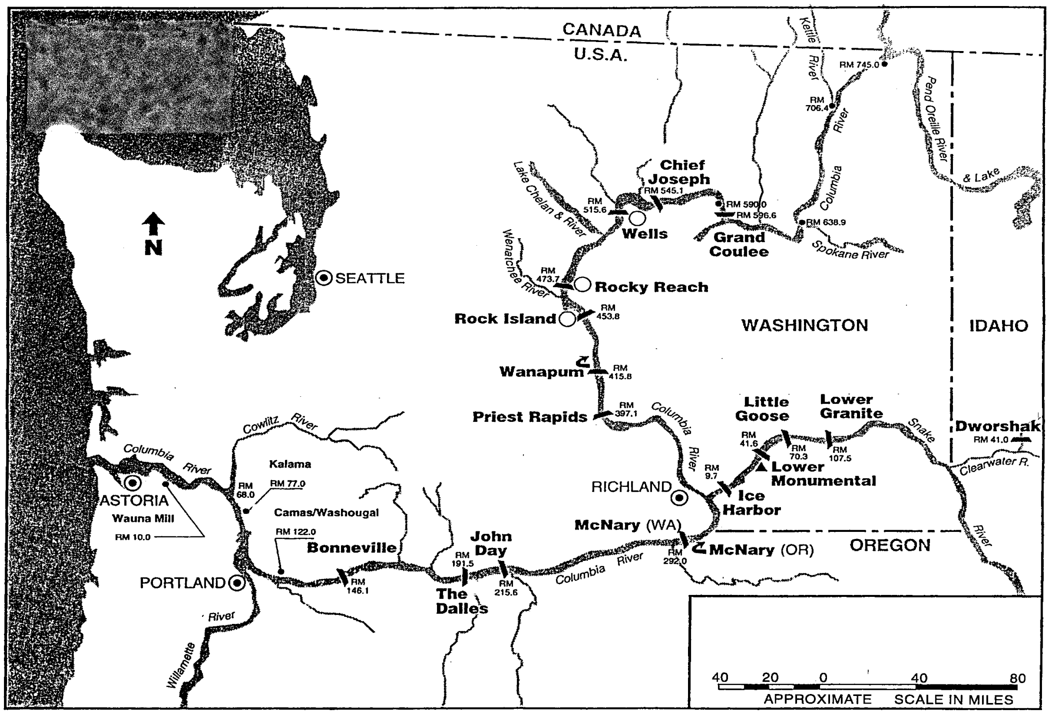


Figure 1-1. The Columbia and Snake Rivers in the study area.

quality improvements consistent with the CWA" (NMFS, 2000). Appendix B of the Biological Opinion charts a course for development of a water quality plan for the mainstem Columbia and Snake Rivers to address CWA objectives. This water quality plan is to be "consistent with the Columbia River and Snake River mainstem total maximum daily load (TMDL) limits that are currently being developed by EPA, the states, and the Tribes." (NMFS, 2000)

The scope of this Problem Assessment and the TMDL to follow is water temperature in the main stem segments of the Columbia River from the Canadian Border to the Pacific Ocean and the Snake River from its confluence with the Salmon River to its confluence with the Columbia River. This TMDL, along with TMDLs that the states are developing for TDG on the mainstems, will serve as the nexus between CWA and ESA, addressing the importance that both Acts place on maintaining ecosystem integrity. This TMDL, required by the CWA to address water quality standards exceedances for temperature will establish the goals for temperature improvements called for in the Biological Opinion pursuant to the ESA. Chapter 2 of the Problem Assessment briefly describes the Columbia Basin. It discusses the factors that likely affect water temperature: geography, climate, hydrology, and development. It then briefly summarizes the status of the beneficial use of the rivers that is greatly effected by elevated temperatures, salmon. Further, it very briefly discusses the Indian Tribes of the Columbia Basin that rely on salmon resources and for whom federal agencies have treaty and trust responsibilities. Chapter 3 of the Problem Assessment discusses the status of water temperature in the Columbia and Snake Rivers, describing processes important to water temperature, the Water Quality Standards that apply to the mainstems, existing temperature data and the results of temperature modeling. Chapter 4 evaluates the effects of elevated temperatures on salmon resources. Finally Chapter 5 brings together the discussions of temperature and salmon to make conclusions on the importance of elevated temperatures in the Columbia and Snake mainstreams to threatened and endangered salmon stocks.

2.0 GENERAL DESCRIPTION OF THE COLUMBIA BASIN

2.1 Geography

The Columbia River drains more than 259,000 square miles of southeastern British Columbia in Canada and the states of Idaho, Oregon, Washington, and Wyoming. The Columbia rises in the Rocky Mountain Trench and flows more than 400 miles through the rugged, glaciated mountains of southeastern British Columbia before it reaches the U.S.-Canada border near Castlegar, British Columbia. It enters the United States from the Okanagan Highland Province, a mountainous area of Precambrian-early Paleozoic marine sediments. The Columbia crosses the western margin of the Columbia Basin—a broad, arid plateau formed by Miocene lava flows of the Columbia Basalt—and flows south across the state of Washington. Near Pasco, Washington, and the confluence with the Snake River, the Columbia turns west, forms the border between Oregon and Washington, and flows more than 300 miles through the Cascade Mountain Range to the Pacific Ocean near Astoria, Oregon.

The headwaters of the Snake River are in Jackson Lake in the Teton Mountains of Wyoming at an elevation of 7,000 feet above sea level. The river flows west across the Snake Plain, which is also a broad, arid plateau formed by Miocene lava flows of the Columbia Basalt. At the western edge of Idaho, it turns north and flows through a deeply incised canyon, emerging near Lewiston, Idaho. At Lewiston, the Snake joins the Clearwater River and flows west through the Paillasse Country of eastern Washington, joining the Columbia near Pasco, Washington. The major tributaries of the Snake in Idaho within this project area are the Clearwater River and the Salmon River.

The Snake River is the Columbia's largest tributary. Other major tributaries in the project area include the Spokane, Yakima, Deschutes, and Willamette Rivers. The Spokane River begins in Lake Coeur d'Alene in Idaho and flows west through eastern Washington, entering the Columbia in Lake Franklin D. Roosevelt (Lake FDR). The Yakima River begins in the Cascade Mountains and flows east and south to join the Columbia near the Tri-Cities. Both the Deschutes and Willamette rivers have their headwaters in Oregon; the Deschutes rises in central Oregon and flows north across lava flows of the Columbia Basalt, while the Willamette begins in the Cascade Mountains and flows west to the Willamette Valley, then north to join the Columbia near Portland, Oregon.

2.2 Climate

The climate of most of the Columbia River drainage is primarily of continental character, with cold winters and hot, dry summers. Precipitation varies widely, depending primarily on topographic influences. The interior Columbia Basin and Snake Plain generally receive less than 15 inches of precipitation annually, while annual precipitation can exceed 100 inches per year in some of the mountainous regions of Canada.

Air temperature also varies considerably, depending on location. Summertime temperatures in the Columbia Basin and Snake Plain exceed 100 °F (37.8 °C) for extended periods. Temperatures at higher elevations remain cooler. Winters are cold throughout the basin and heavy snow falls in the mountains. The snowbank accumulates throughout the winter months as a result of frequent passage of storm systems from the Pacific Ocean. Some of the snowbank is incorporated into the extensive system of glaciers in the basin; however, between the months of March and June, depending on elevation, much of the snowbank begins to melt. The resulting hydro graph is typical of a snowbell regime.

West of the Cascade Mountains, which includes the lower 150 miles of the Columbia River and all of the Willamette River, the climate has a more maritime character. Winter air temperatures at lower elevations are seldom below freezing, and summer air temperatures are seldom above 100 °F (37.8 °C) for long periods. Average annual precipitation west of the Cascades is more than 40 inches in most areas. Precipitation recorded at coastal stations is typically higher. Below about 5,000 feet, most of the precipitation falls as rain, with 70 percent or more falling between October and March.

2.3 Hydrology

The hydrology of the Columbia River system has been modified by the construction of numerous hydroelectric, irrigation, flood control, and transportation projects. However, the hydro graph still has the characteristics of a snow melt regime. Stream flows are low during the winter, and increase beginning in spring and early summer as the snowbank melts. Melting of the winter snow pack generally takes place in May and June, and stream flows increase until the snow pack can no longer support high flows. Flows then recede gradually during the summer and are derived from reservoir storage and from ground water recession into the fall and winter. Occasionally, runoff from winter storms augments the base flow and can increase river discharge rapidly.

Mean annual river discharges for key locations on the main stem Columbia and Snake River and selected tributaries are shown in Table 2-1.

Table 2-1. Mean annual discharges at selected sites on the main stem Columbia and Snake Rivers

Station Name	Gage #	Station Location		Period of Record	Average Flow (cfs)
		Latitude	Longitude		
Snake River near An atone, Washington	13334300	46° 05'50"	116° 58'36"	1958-1995	34800
Tucannon near Starbuck, Washington	13344500	46°30'20"	118° 03'55	1914-1996	176
Palouse River near Hooper, Washington	13351000	46°15'02"	118° 52'55	1898-1996	588
Snake River below Ice Harbor Dam	13353000	46°15'02"	118° 52'55"	1913-1992	53400
Columbia River at the International Boundary	12399500	49° 00'03"	117° 37'42"	1938-1996	99200
Columbia River at Grand Coulee	12436500	47° 57'56"	118° 58'54"	1923-1996	108200
Columbia River at Bridgeport, Washington	12438000	48° 00'24"	119° 39'51"	1952-1993	110200
Okanogan River at Malott, Washington	12447200	48° 16' 53"	119° 42' 12"	1965-1996	3050
Methow River near Pateros, Washington	12449950	48° 04' 39"	119° 59' 02"	1959-1996	1560
Columbia River below Wells Dam	12450700	47° 56'48"	119° 51'56"	1968-1996	109400
Columbia River at Rocky Reach Dam	12453700	47° 31' 28"	120° 18'04"	1961-1996	113200
Wenatchee River at Monitor, Washington	12462500	47° 29' 58"	120° 25' 24"	1962-1996	3250
Columbia River below Rock Island Dam	12462600	47° 19'57"	120° 04'48"	1961-1996	116300
Crab Creek near Moses Lake, Washington	12467000	47° 11' 22"	119° 15' 53"	1942-1996	63
Columbia River below Priest Rapids Dam	12472800	46° 37'44"	119° 51'49"	1918-1996	118400
Walla Walla River at Touchet, Washington	14018500	46° 01' 40"	118° 43' 43"	1951-1996	568
John Day River at McDonald Ferry, Oregon	14048000	45° 35' 16"	120° 24' 30"	1904-1996	2080
Deschutes River at Moody, near Biggs, Oregon	14103000	45° 37' 20"	120° 54' 54"	1907-1996	5800

Station Name	Gage #	Station Location		Period of Record	Average Flow (cfs)
		Latitude	Longitude		
Columbia River at the Dalles	14105700	45° 36'27"	121° 10'20"	1878-1996	191000

2.4 Salmon Resources

According to the Independent Scientific Group (1996), 200 distinct anadromous salmon stocks returned several million adult salmon and steelhead to the Columbia River prior to development of the basin. All five native eastern Pacific salmon species historically returned to the Columbia River, but today (with some exceptions) most chum, pink and wild coho stocks are extinct and the other species are at risk of extinction. In fact, 69 of the 200 stocks have been identified as extinct and 75 others are at risk of extinction in various parts of the basin (ISG, 1996) Historical estimates of average salmon runs in the portion of the Columbia Basin upstream of Bonneville Dam exceeded 5 to 11 million fish, but, as of 1995, average returns above Bonneville Dam were fewer than 500,000 fish and 80% of those were from hatcheries (CRITFC, 1995).The Independent Scientific Group concluded that the "development of the Columbia River for hydropower, irrigation, navigation and other purposes has led to a reduction in both the quantity and quality of salmon habitat, and most critical, a disruption in the continuum of that habitat" (ISC, 1996).

Table 2-2 lists the 12 stocks (or species under the ESA) listed by NMFS under the ESA and present within the TMDL project area.

Table 2-2 : The 12 species of Columbia Basin Salmonids listed under the Endangered Species Act and located in waters within the TMDL project area.

Listed Species	Date Listed/Federal Register Notice	Date Critical Habitat Designated/ FR Notice
Snake River Spring/Summer Chinook (*Oncorhynchus tshawytscha*)	04/22/92 [58 FR 14653]	12/28/93 [64 FR 57399] 10/2593 [64 FR 57399]
Snake River Fall Chinook (*O. tshawytscha*)	04/22/92 [57 FR 14653]	12/28/93 [58 FR 68543]
Upper Columbia River Spring Chinook (*O. tshawytscha*)	03/24/99 [64 FR 14308]	02/16/00 [65 FR 7764]
Upper Willamette River Chinook (*O. tshawytscha*)	03/24/99 [64 FR 14308]	02/16/00 [65 FR 7764]
Lower Columbia River Chinook (*O. tshawytscha*)	03/24/99 [64 FR 14308]	02/16/00 [65 FR 7764]
Snake River Steelhead (*O. mykiss*)	08/18/97 [62 FR 43937]	02/16/00 [65 FR 7764]
Upper Columbia River Steelhead (*O. mykiss*)	08/18/97 [62 FR 43937]	02/16/00 [65 FR 7764]
Middle Columbia River Steelhead (*O. mykiss*)	03/25/99 [64 FR 14517]	02/16/00 [65 FR 7764]

Upper Willamette River Steelhead (*O. mykiss*)	03/25/99 [64 FR 14517]	02/16/00 [65 FR 7764]
Lower Columbia River Steelhead (*O. mykiss*)	03/19/98 [63 FR 13347]	02/16/00 [65 FR 7764]
Columbia River chum (*O. keta*)	03/25/99 [64 FR 14508]	02/16/00 [65 FR 7764]
Snake River sockeye (*O. nerka*)	11/20/91 [56 FR 58619]	12/28/93 [58 FR 68543]

2.5 Indian Tribes

Thirteen tribes, listed below, have management authority for fish, wildlife and water resources within their reservations, as well as other legal rights included in treaties and executive orders:

Confederated Tribes of the Colville Reservation;
Confederated Tribes of the Umatilla Indian Reservation;
Confederated Tribes of the Warm Springs Reservation;
Confederated Tribes and Bands of the Yakama Nation;
Nez Perce Tribe;
Spokane Tribe of Indians;
Couer d' Alene Tribe;
Kalispel Tribe of Indians;
Kootenai Tribe of Idaho;
Salish-Kootenai Tribes of the Flathead Indian Reservation;
Shoshone-Bannock Tribes of the Fort Hall Reservation;
Burns-Paiute Tribe;
Shoshone-Paiute Tribes of the Duck Valley Reservation.

Four of these tribes, Confederated Tribes of the Umatilla Indian Reservation, Confederated Tribes of the Warm Springs Reservation, Confederated Tribes and Bands of the Yakama Nation, and Nez Perce Tribe reserved their rights to take anadromous fish in treaties with the United States in 1855. The tribes gave up control of large tracts of land but retained ownership of the salmon runs that are vital to their culture (CRITFC, 1995). The tribes reserved the right to take fish within their reservations, at all usual and accustomed fishing sites on lands ceded to the United States government and at all the usual and accustomed fishing sites outside the reservation or ceded areas, but these rights are meaningless if there are no fish to be taken (CRITFC, 1995).

Two Tribes, the Confederated Tribes of the Colville Reservation, and the Spokane Tribe of Indians have reservations that include portions of the Columbia River. Both tribes have developed water quality standards for the potions of the Columbia within their reservations. The Colville WQS have been promulgated by EPA and are national standards. The Spokane standards, at this point are reservation standards, but will be submitted to EPA for promulgation.

Salmon are intrinsic to the culture and identity of the Indian Tribes of the Columbia Basin. Salmon are part of their spiritual and cultural identity. Historically the tribes were wealthy people because of flourishing economies based on salmon. Salmon was the primary food source of the tribes and continues to be essential to their nutritional health. The tribes believe that without the salmon returning to their rivers and stream, they would cease to be Indian people (CRITFC, 1995).

2.6 Water Resources Development

The Columbia River and its tributaries have been developed to a high degree. The only segment of the Columbia River above Bonneville Dam that remains unimpounded is the Hanford Reach between Priest Rapids Dam (Columbia River Mile 397.1) and the confluence with the Snake River (Columbia River Mile 324.3). The 11 main stem hydroelectric projects in the United States (Table 2-3), from Grand Coulee Dam to Bonneville Dam, develop approximately 1,240 feet of the 1,290 feet of hydraulic head available in this segment of the Columbia River main stem. Hydroelectric and flow control projects on the main stem of the Columbia River and its tributaries in Canada have resulted in significant control of flow in the Upper Columbia and Kootenai River Basins. The Snake River is also nearly fully developed, with 19 dams on the main stem, four of them in the TMDL project area.

Table 2-3. Hydroelectric projects on the main stem Columbia and Snake Riversincluded in the scope of the analysis

Project	River Mile	Start of Operation	Generating Capacity (megawatts)	Storage Capacity (1000s acre-feet)
Columbia River				
Grand Coulee	596.6	1942	6,494	8,290
Chief Joseph	545.1	1961	2,069	588
Wells	515.8	1967	774	281
Rocky Reach	473.7	1961	1,347	440
Rock Island	453.4	1933	622	132
Wanapum	415.8	1963	1,038	710
Priest Rapids	397.1	1961	907	231
McNary	292.0	1957	980	1,295
John Day	215.6	1971	2,160	2,294
The Dalles	191.5	1960	1,780	311
Bonneville	146.1	1938	1,050	761
Snake River				
Lower Granite	107.5	1975	810	474
Little Goose	70.3	1970	810	541
Lower Monumental	41.6	1969	810	351
Ice Harbor	9.7	1962	603	400

These dams and reservoirs serve many purposes, including irrigation, navigation, flood control, municipal and industrial water supply, recreation, and hydroelectric power generation. There are approximately 7 million acres of irrigated farmlands in the Columbia River Basin, including 3.3 million acres in Idaho, 0.4 million acres in Montana, 1.9 million acres in Washington, and 1.3 million acres in Oregon (Bonneville Power Administration et al., 1994). The system has the capacity for generating more than 20,000 megawatts of hydroelectric energy, and slack-water navigation now extends more than 460 river miles from the mouth at Astoria, Oregon, to Lewiston, Idaho.

In the United States, federal agencies, private power companies, and public utility districts own the dams in the Columbia River Basin. The Columbia Treaty between the United States and Canada governs transboundary issues related to the operation of dams and reservoirs on the Columbia River system in Canada.

2.7 Population/Land Use/Economy

The Columbia Basin includes sparsely populated rural areas and dense metropolitan areas. Much of the Columbia Basin is located east of the Cascade Mountains. This area is sparsely populated with a density of 11 people per square mile compared to a national average of 70 people per square mile (ICBEMP,2000). Based on the 1998 census, 3.3 million people live in the portion of the basin east of the Cascade Mountains. Nearly half of this population lives in 12 of the 100 counties east of the Cascades. Only six counties have sufficient population to be classified as metropolitan counties. Thirty one percent of the residents east of the Cascades live in urban areas compared to the national average of over 77% and over 90% of the 470 communities east of the Cascades are considered to be rural communities (ICBEMP, 2000). There are 2 cities east of the Cascades with populations over 100,000 people: Spokane, WA; and Boise, ID. (USCB, 2000).

West of the Cascade Mountains there is considerable rural land in southwest WA, the Willamette Valley of Oregon and Northwest Oregon but there is also considerably more metropolitan area than east of the mountains. A much greater percentage of the population lives in urban centers west of the mountains. The Portland, OR/ Vancouver, WA primary metropolitan statistical area (PMSA) had a population of 1,819,000 in July, 1998, while the Salem, OR PMSA had 330,000 people and the Eugene/Springfield, OR PMSA had 314,000 people (USCB, 2000).

Agriculture and forestry are important economic sectors throughout the basin.
Table 2-4, compiled from the Interior Columbia Basin Ecosystem Management Project Supplemental Draft EIS (ICBEMP, 2000), compares employment in economic sectors from the Columbia Basin east of the Cascade Mountains with national averages. The table shows that agricultural services, mining, wood products manufacturing (SIC 24), and farm employment all exceed the national averages. Recreation, while not included in the table is estimated to generate about 4.5 % of employment in the ICBEMP area (ICBEMP, 2000).

Table 2-5, compiled from McGinnis et al (1996), Illustrates the employment by economic sector in the metropolitan counties in the Portland Oregon, area. Forestry and agriculture are also very important in these counties. Manufacturing, construction and service industries appear to be more important in these metropolitan counties than in the rural areas east of the mountains.

An important land use feature of the basin is that large areas of land are administered by governments. This is especially true east of the Cascade Mountains. This portion of the Basin comprises 144 million acres and 75 million of those acres are administered by the Forest Service or the Bureau of Land Management (ICBEMP, 2000).

Table 2-4 : Comparison of employment in economic sectors in the United States to the interior Columbia Basin east of the Cascade Mountains. Numbers in bold indicate that the basin average is higher than the national average.

Industry	**United States (%)**	**Eastern Basin Average (%)**[1]
Agriculture services	1.24	**2.20**
Mining	0.58	**0.59**
Construction	5.33	**6.09**
Manufacturing	12.63	10.27
SIC 24[2]	0.57[3]	**2.00**
Transportation	4.73	3.95
Trade	21.48	**21.96**
FIRE[4]	7.41	5.32
Services	30.44	25.54
Government (all)	14.24	**15.46**
State and local	10.88	**12.32**
Farm Employment	1.93	**6.56**

[1] Numbers are for the interior Columbia River Basin area assessed by the Interior Columbia Basin Ecosystem Assessment Project.

[2] SIC 24 - Standard Industrial Classification for lumber and wood products. Manufacturing number includes SIC 24.

[3] National SIC 24 data from 1990 data.

[4] FIRE - Finance, insurance and real estate.

Table 2-5 : Employment in economic sectors in the metropolitan counties near Portland, OR in 1991.

Industry	Clackamas Co.	Columbia Co.	Multnomah Co.	Washington Co.	Yamhill Co.
Agriculture, Forestry, Fish	4.5%	8.2%	0.6%	2.7%	10.2%
Mining	0.1%	0.3%	0.1%	0.1%	0.3%
Construction	8.9%	6.1%	6.0%	7.9%	7.6%
Manufacturing	12.5%	20.7%	11.8%	19.4%	18.0%
Transportation, Communication, Utilities	3.1%	9.8%	6.3%	2.6%	2.8%
Trade	22.7%	12.1%	17.4%	20.6%	12.3%
FIRE	7.5%	4.3%	8.4%	8.1%	7.2%
Services	29.0%	22.7%	35.5%	30.8%	28.3%
Government	10.4%	14.2%	11.0%	6.6%	11.3%
other	1.3%	1.4%	2.9%	1.0%	2.0%

3.0 WATER TEMPERATURE ASSESSMENT

3.1 General

Water temperature is an important water quality component of habitat for salmon and other cold water organisms. Water quality standards have been developed by the states and tribes specifically to protect cold-water aquatic life, including salmonids, in the Columbia and Snake Rivers. Salmonids evolved to take advantage of the natural cold, freshwater environments of the Pacific Northwest. Temperature directly governs their metabolic rate and directly influences their life history. Natural or anthropogenic fluctuations in water temperature can induce a wide array of behavioral and physiological responses in these fish. These fluctuations may lead to impaired functioning of the individual and decreased viability at the organism, population, and species level. Feeding, growth, resistance to disease, successful reproduction, sufficient activity for competition and predator avoidance, and successful migrations are all necessary for survival and as discussed in Chapter 4, can all be affected by temperature.

The water temperature regimes of the Columbia and Snakes Rivers have been altered significantly by human development along the main stems themselves and throughout the basins. Natural ecosystem processes and characteristics are essential to maintaining the generally cool water temperature regime in which salmon evolved in the hot, dry summer climate of the Columbia Plateau and Snake River Plain. Some of the processes and characteristics that are essential to maintaining the temperature regimes of streams and rivers are the flow characteristics (e.g. velocity, width to depth ratio), riparian shade, advection of heat, groundwater input and hyporheic interchange in the alluvial sediments of the channel and flood plains. Riparian shade was probably not a significant factor on the main stems of the Columbia and Snake because of their width and propensity to flood, but it may have been a factor in localized areas, providing cool near shore refugia to fish during hot summer days. The other factors have played a role in the temperature regimes of the Columbia and Snake

Rivers and have been affected by human development.

The dams on the Columbia and Snake Rivers have greatly altered the channel geometry of the rivers and thereby the flow characteristics. Previous studies of the Columbia and Snake Rivers (Davidson, 1964; Jaske and Synoground, 1970; Moore, 1969; Independent Scientific Group[5], 1996) have identified the construction and operation of hydroelectric facilities as having a major impact on the thermal regime of the Columbia and Snake Rivers. Jaske and Synoground (1970) concluded that the construction of river-run reservoirs on the main stem of the Columbia River caused no significant changes in the average annual water temperature, but that the operation of Lake FDR, the reservoir behind Grand Coulee Dam, delayed the time of the peak summer temperature in the Columbia River at Rock Island Dam by about 30 days. Moore (1969) found that both Lake FDR and Brownlee Reservoir on the Snake River caused cooling in the spring and summer and warming in fall and winter. The Independent Scientific Group (1996) concluded that "main stem reservoirs in the Snake and Columbia rivers have created shallow, slowly moving reaches of shorelines where solar heating has raised temperature of salmon rearing habitat above tolerable levels" and that water temperatures in the Columbia River Basin have been altered by development and are, at times, suboptimal or clearly detrimental for salmonids.

The dams on the two rivers have also greatly simplified the complex and dynamic gradient of habitat types typical of the pre-dam rivers. The ISG describes three important spatial dimensions to a natural river system. The **riverine** system is a longitudinal continuum of runs, riffles and pools. The **riparian** zone is a lateral array of habitats from the middle of the main channel through various side and flood channels and wetlands to flood plains and the uplands of the valley wall. The **hyporheic** zone is a "latticework of underground (hypogean) habitats associated with the flow of the river through the alluvium (bed sediments) of the channel and the flood plains." (ISG, 1996) The dams flooded most of the riverine, riparian and hyporheic features of the natural lotic system, essentially creating a series of more simple lentic zones between dams with little spatial complexity. Critical habitat for salmonids existed in all three of the habitat types, but the hyporheic zone was also very important in the regulation of water temperature.

According to the ISG, water flow through the interstitial spaces of the hyporheic zone in the river bed and the flood plain and then back to the river plays an especially important role in salmon ecology. The hyporheic flow returning to the river bed is a source of oxygen for salmon eggs and a source of nutrients to produce food for salmon larvae, but more important to this discussion, hyporheic flow is an important moderator of water temperature. In comparison to surface temperatures, hyporheic flow is cool in the summer and warm in the winter (ISG, 1996) According to the ISG, hyporheic flow appears to be critical to the high desert rivers of the Columbia Plateau where late summer water temperatures may be too high for salmon. The hyporheic flow provides cool places in the river for salmon to seek refuge on hot summer days. The ISG stated that "alluvial reaches are arrayed along the stream continuum like beads on a string" (ISG, 1996). As such they provided areas of hyporheic return flows to the river that provided salmon with cool water refugia all along the river length.

Surface and groundwater flows tributary to the Snake and Columbia rivers are sources of advected thermal energy that have the potential for modifying the thermal energy budget of the main stem. Moore (1969) studied the impact of the Clearwater and Salmon rivers on the main stem Snake and the Kootenai and Pend Oreille rivers on the Columbia during 1967 and 1968. He found that the Clearwater and Salmon rivers cooled the Snake River during some of this period, but at no time did they produce a warming effect. Viewing the Snake as a tributary to the Columbia, Moore (1969) and Jaske and Synoground (1970) concluded that the advected thermal energy from the Snake River increased the temperature of Columbia River during the summer. Moore (1969) estimated that the maximum temperature increase was of the order of 1 °C during 1967 and 1968, while Jaske and Synoground (1970) estimated the annual thermal energy contribution of the Snake River to the Columbia River to be on the order of 4,000 megawatts. The Independent Scientific Group (1996)

[5] The Independent Scientific Group comprised nine experts in fishery sciences commissioned by the Northwest Power Planning Council to (1) perform an independent review of the science underlying salmon and steelhead recovery efforts and Columbia River Basin ecosystem health, and (2) develop a conceptual foundation that could form the basis for program measures and basinwide fish and wildlife management.

discusses temperature in the tributaries primarily as it relates to habitat in individual tributaries. The group concludes that high temperatures in the late summer and fall are detrimental to both juvenile and adult salmon in the main stem and tributaries, but does not discuss the impact of the tributaries on the thermal energy budget of the main stem.

Wastewater discharges are also sources of advected heat to the main stems. There are 378 permitted discharges to the main stem of the Columbia. Most of these are very small in comparison to the river flow.

Nonpoint sources of thermal energy are a source of advected heat to the main stems. Nonpoint sources encompass all diffuse sources of heat to the basin. Typical nonpoint sources include heat added to streams because of the reduction of riparian vegetation, heat from changing the width to depth ratio of tributaries through the accretion of sediments in the stream channels, and heat from irrigation return flows. Agriculture, forestry, urban development and surface transportation can be important sources of nonpoint heat from the basin to the main stems if they are conducted in a manner that removes riparian vegetation or increases sediment input to the streams. The nonpoint thermal energy enters the main stems primarily from the tributaries.

Human activities also effect the temperature regime of streams by altering the flow regime. For example, agriculture, forestry, and urban development can develop impervious surfaces, drain acreage for cropping and remove vegetation that tends to facilitate retention of water in the watershed. These actions reduce the retention of water in the soil and groundwater and accelerate the flow of precipitated water to the stream system. As a result, the streams are flashy, receiving most of there flow shortly after precipitation. This reduces the amount of groundwater available to be released to the stream during hot, low flow periods: groundwater that tends to cool the stream. Use of surface and ground water for water supply tends to affect the stream flow and temperature regimes in the same manner.

All of these forces are at play in the temperature regimes of the Columbia and Snake main stems. The purpose of this temperature assessment is to characterize the temperature of the rivers in comparison to the water quality standards, and describe the linkages between the various sources and causes of heat and the rivers' response in terms of in stream water temperature.

3.2 Water Quality Standards

Water Quality Standards (WQS) for lakes, streams, rivers, wetlands and other surface waters are established by States and certain Indian Tribes under the federal Clean Water Act (CWA). Water Quality Standards define the water quality goals of a water body by designating the use or uses to be made of the water, by setting criteria necessary to protect the uses and by preventing degradation of water quality through antidegradation provisions. They play an important role in protecting the quality of the waters of the United States by establishing the target water quality for waste water discharges, watershed management plans and TMDLs. Three states and one Indian tribe have WQS standards promulgated pursuant to section 303(c) of the CWA that apply to the Columbia and Snake Rivers: Idaho, Oregon, Washington and the Confederated Tribes of the Colville Reservation. Another Indian tribe, the Spokane Tribe of Indians has WQS for the Columbia River that have been adopted by the tribe but not yet approved by EPA. The WQS for each state and tribe for the portions of the Columbia and Snake Rivers subject to this TMDL are summarized below:

Idaho

The WQS for Idaho are established in the Idaho Administrative Code, IDAPA 16.01.02, "Water Quality Standards and Wastewater Treatment Requirements." Section 130.02 establishes the designated aquatic life uses of the Snake River between the Salmon River and the Washington Border as cold water. Section 100.01.a defines cold water as "water quality appropriate for the protection and maintenance of a viable aquatic life community for cold water species." Section 250.02.b establishes the water quality criteria for temperature for the cold water aquatic life use designation as "Water temperature of twenty-two (22) °C or less with a maximum daily average of no greater than nineteen (19) °C."

Section 070.06 discusses natural background conditions: "Where natural background conditions from natural surface or groundwater sources exceed any applicable water quality criteria as determined by the Department, that background level shall become the applicable site-specific water quality criteria. Natural background means any physical, chemical, biological, or radiological condition existing in a water body due only to non-human sources. Natural background shall be established according to protocols established or approved by the Department consistent with 40 CFR 131.11. The Department may require additional or continuing monitoring of natural conditions."

Oregon

The WQS for Oregon are established in the Oregon Administrative Rules,

OAR 340-040-0001 to OAR 340-040-0210, "State-Wide Water Quality Management Plan; Beneficial Uses, Policies, Standards, and Treatment Criteria for Oregon."

The Snake River in Oregon from the OR/WA Border at river mile 176 to the Salmon River at river mile 188 is included in this TMDL. The beneficial uses most sensitive to temperature in that reach are "Anadromous Fish Passage", "Salmonid Fish Rearing" and "Salmonid Fish Spawning". The temperature criteria applicable to this reach are:"

> Unless specifically allowed under a Department-approved surface water temperature management plan as required under OAR 340-41-026(3)(a)(D), no measurable surface water temperature increase resulting from anthropogenic activities is allowed:
>
> (i) in a basin for which salmonid rearing is a designated beneficial use, and in which surface water temperatures exceed 64.0 °F (17.8 °C);
>
> (ii) In waters and periods of the year determined by the Department to support native salmonid spawning, egg incubation, and fry emergence from the egg and from the gravels in a basin which exceeds 55 °F (12.8 °C)."

The period of the year designated by the Oregon Department of Environmental Quality for the protection of salmonid spawning, egg incubation, and fry emergence in this area is October 1 through June 30.

The numeric temperature criteria are measured as the seven-day moving average of the daily maximum temperatures. If there is insufficient data to establish a seven-day average of maximum temperatures, the numeric criterion is applied as an instantaneous maximum. A measurable surface water increase is defined as 0.25 °F. Anthropogenic is defined to mean that which results from human activity.

The segment of the Columbia River which serves as the OR/WA border is included in this TMDL and subject to OR WQS. It stretches from the mouth of the river at river mile 0 to river mile 309. The temperature sensitive beneficial uses vary from segment to segment along that reach as shown in Table 3-1.

Table 3-1: Oregon designated uses along the Columbia River

Basin/Columbia River Miles	Anadromous Fish Passage	Salmonid Fish Rearing	Salmonid Fish Spawning	Shad and Sturgeon Spawning/Rearing
Lower Columbia / 0-86	X	X	X	
Willamette / 86-120	X	X	X	
Sandy / 120-147	X	X		
Hood / 147-203	X	X	X	X
Deschutes /203-218	X	X		
John Day / 218-247	X	X	X	
Umatilla / 247309	X	Trout	Trout	

The temperature criterion applicable to the Columbia River in Oregon is:

"Unless specifically allowed under a Department-approved surface water temperature management plan as required under OAR 340-41-026(3)(a)(D), no measurable surface water temperature increase resulting from anthropogenic activities is allowed in the Columbia River or its associated sloughs and channels from the mouth to river mile 309 when surface water temperatures exceed 68.0 °F (20.0 °C)."

Washington

The WQS for Washington are established in the Washington Administrative Code, Chapter 173-201A WAC, "Water Quality Standards for Surface Waters of the State of Washington." Waters of the state are categorized in the Water Quality Standards into classes based on the character of the uses of each water body. The designated uses of the Columbia and Snakes rivers most sensitive to temperature are salmonid migration, rearing, spawning and harvesting; and other fish migration, rearing, spawning and harvesting. The most protected class on the Columbia Snake is "AA" or 'extraordinary' and this applies only to Lake Roosevelt. The rest of the river is grouped into class "A" or 'excellent'. Under each of these classes, the temperature standard is applicable at any time of day or night. It applies toward fish protection in all portions of the rivers, including fish passage facilities and fish ladders within the dam structures.

Each class of water is assigned a maximum temperature. For class "AA" waters it is16 centigrade. For class "A" waters it is 18 °C. However, for the Columbia River below Priest Rapids dam and for the entire Snake River, a special condition applies which is two degrees higher, 20 °C.

"Natural Conditions" for temperature means water temperatures as they are best assessed to have existed before any human-caused pollution or alterations. If the Snake or Columbia Rivers are found to have a natural condition higher than the standard, no additional temperature pollution can be added that will result in raising the temperature more than 0.3 °C. This would be measured as the cumulative impact of all dischargers as measured by the far-field TMDL model.

Incremental temperature increases are allowed when existing temperatures are below the standard as long as the standard maximum temperature is not exceeded. This is different for different parts of the river. Some of these increases are expressed as formulas. Generally, they are more restrictive for the upper portions of the rivers. The temperature criteria and incremental temperature increases applicable to the Snake and Columbia Rivers in Washington are summarized in Table 3-2.

Table 3-2: **Washington Water Quality Criteria along the Columbia River**

Water Body	*Criteria*
Columbia Main Stem from the coast to the Oregon/Washington Border	"Temperature shall not exceed 20 °C (68 F) due to human activities. When natural conditions exceed 20 °C (68 F) no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3 °C (0.5 F) nor shall such temperature increases, at any time exceed 0.3 °C (0.5 F) due to a single source or 1.1 °C (2.0 F) due to all such activities combined."
Columbia Main Stem Priest Rapids Dam to OR/WA Border	"Temperature shall not exceed 20 °C (68 F) due to human activities. When natural conditions exceed 20 °C (68 F) no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3 °C (0.5 F) nor shall such temperature increases, at any time exceed t=34/(T+9)."
Columbia Main Stem Priest Rapids to Grand Coulee	"Temperature shall not exceed 18 °C (64.4 F) due to human activities. When natural conditions exceed 18 °C (64.4 F) no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3 °C (0.5 F). Incremental temperature increases resulting from point source activities shall not, at any time, exceed t=28/(T+7). Incremental increases resulting from nonpoint source activities shall not exceed 2.8 °C (5.4 F)."
Columbia Main Stem Above Grand Coulee	"Temperature shall not exceed 16 °C (60.8 F) due to human activities. When natural conditions exceed 16 °C (60.8 F) no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3 °C (0.5 F). Incremental temperature increases resulting from point source activities shall not, at any time, exceed t=23/(T+5). Incremental increases resulting from nonpoint source activities shall not exceed 2.8 °C (5.4 F)."
Snake Main Stem from the Washington/Oregon Border to the Clearwater River.	"Temperature shall not exceed 20 °C (68 F) due to human activities. When natural conditions exceed 20 °C (68 F) no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3 °C (0.5 F) nor shall such temperature increases, at any time exceed 0.3 °C (0.5 F) due to a single source or 1.1 °C (2.0 F) due to all such activities combined."
Snake Main Stem from the Clearwater River to the Columbia River.	"Temperature shall not exceed 20 °C (68 F) due to human activities. When natural conditions exceed 20 °C (68 F) no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3 °C (0.5 F) nor shall such temperature increases, at any time exceed t=34/(T+9)."

t = the maximum permissible temperature increase measured at a mixing zone boundary

T = the background temperature as measured at a point or points unaffected by the discharge and representative of the highest ambient water temperature in the vicinity of the discharge.

Confederated Tribes of the Colville Reservation

The WQS for the Confederated Tribes of the Colville Reservation were promulgated by EPA at 40 CFR 131.135. These standards apply to the Columbia River from the northern boundary of the reservation downstream to Wells Dam. The Columbia River is designated as "Class I (Extraordinary)" from the Northern Border of the Reservation to Chief Joseph Dam and "Class II (Excellent)" from Chief Joseph Dam to Wells Dam. The designated uses most sensitive to temperature are "Fish and shellfish: Salmonid migration, rearing, spawning and harvesting: other fish migration, rearing, spawning and harvesting." The temperature criterion for Class I waters is:

> "(D) Temperature - shall not exceed 16.0 °C due to human activities. Temperature increases shall not, at any time, exceed t=23/(T+5).
>
> (1) When natural conditions exceed 16.0 °C, no temperature increase will be allowed which will raise the receiving water by greater than 0.3 °C.
>
> (2) For purposes hereof, "t" represents the permissive temperature change across the dilution zone: and "T" represents the highest existing temperature in this water classification outside of any dilution zone.
>
> (3) Provided that temperature increase resulting from nonpoint source activities shall not exceed 2.8 °C, and the maximum water temperature shall

not exceed 16.3 °C."

The temperature criterion for Class II waters is:

"Temperature - shall not exceed 18.0 °C due to human activities. Temperature increases shall not, at any time, exceed $t=28/(T+7)$.

(1) When natural conditions exceed 18.0 °C, no temperature increase will be allowed which will raise the receiving water by greater than 0.3 °C.

(2) For purposes hereof, "t" represents the permissive temperature change across the dilution zone: and "T" represents the highest existing temperature in this water classification outside of any dilution zone.

(3) Provided that temperature increase resulting from nonpoint source activities shall not exceed 2.8 °C, and the maximum water temperature shall not exceed 18.3 °C."

Table 3.3 summarizes the criteria that apply to the Columbia and Snake Rivers.

Table 3.3: Summary of Water Quality Criteria for the Columbia and Snake Rivers

River Reach	Idaho	Oregon (7 day running ave of the daily maximums)	Washington (Maximum)	Colville Reservation (Maximum)
Snake: Salmon R to OR Border	19 C daily ave 22 C max	Oct 1 to June 30 - 12.8 C or natural July 1 to Sep 30 17.8 or natural		
Snake: Or Border to Clearwater R.	19 C daily ave 22 C max		20 C or natural + .3 C	
Snake: Clearwater to mouth			20 C or natural + .3 C	
Columbia: Can Border to Grand Coulee			16 C or Natural + .3 C	16 C or Natural + .3 C*
Grand Coulee to Chief Joseph			18 C or Natural + .3 C	16 C or Natural + .3 C
Chief Joseph to Wells			18 C or Natural + .3 C	18 C or Natural + .3 C
Wells to Priest Rapids			18 C or Natural + .3 C	
Priest Rapids to OR Border			20 C or Natural + .3 C	
OR Border to mouth		20 C or natural	20 C or Natural + .3 C	

* Applies from the Northern Boundary of the Colville Reservation (approximately River Mile 721) to Grand Coulee Dam

3.3 Existing Data

3.3.1 Data Availability and Quality

There is a considerable record of temperature data from the Columbia and Snake Rivers. McKenzie and Laenen (1998) assembled temperature data from 84 stations along the two rivers within the study area of this TMDL. They collected data from all the dams along the rivers, a number of stations monitored by the United States Geological Survey and numerous other stations. Some of the data sets are quite extensive. For example, temperature data collection at the Rock Island Dam scroll case has been continuous since 1933 when it was the only dam on the river. Likewise, temperature data collection at the Bonneville Dam scroll case has been continuous since 1938 when there were only 2 dams on the river. These two data sets are of particular importance because they may represent the only temperature data collected before the construction of storage reservoirs that regulate the flow of the river. There were no dams upstream of Rock Island Dam for 9 years and there were no dams within 300 miles of Bonneville Dam for 18 years. While these dams may have had some effect on temperature, these two data records may be the best indication of the temperature regime of the Columbia River before the dams were built.

While scroll case data represents the longest continuous temperature record along the river and may be the only data from the river before flow regulation by dams, it is not clear how well scroll case temperature measurements at each project represent in-river temperature in the vicinity. The scroll case is located within the interior of the dam, usually just upstream from the blades of the turbine. Water temperature is often measured at an outlet pipe from the scroll case, prior to its use for cooling water. An EPA team visited six dams on the Columbia, Snake and Clearwater Rivers (McNary, Ice Harbor, Lower Monumental, Little Goose, Lower Granite and Dworshack) to observe and evaluate the temperature monitoring stations. They "observed little or no consistency in type of measurement instruments, location of instruments, number of instruments, and quality control for instruments and recording. For this reason, the accuracy of scroll case temperature monitoring likely varies significantly between facilities" (Cope, 2001). This does not mean that the scroll case data should not be used. The quality of the data varies and it should be used cautiously, but these long records of scroll case data can provide valuable insights on the temperature regime of the river system.

McKenzie and Laenen (1998) found the Rock Island scroll case data to be among the better data sets from the mid-Columbia. They compared the Rock Island data to data made available by Pacific States Marine Fisheries Council collected in 1966, 1971, and 1972 at the forebay, spillway and mid channel and found no bias for either site. The minimum, median, and maximum variability between the two data sets was 0.0, 0.2, and 0.8°C. Figure 3-1 depicts the scroll case data from Rock Island Dam for 1933 through 1937. These data indicate that prior to flow regulation at Grand Coulee Dam, peak summer river temperatures exceeded 18 °C.

Figure 3-1. Water Temperature in the Scroll Case of Rock Island Dam 1933-1937

The other long historical temperature record is from the Bonneville Dam scroll case. Mackenzie and Laenen (1998) found this data to be "relatively good for the entire period, however they are stepped throughout and may not be representative of the river cross section." They compared scroll case and tail race data from 1972-1997 and found the scroll case data to be about 0.5-1.5°C higher. The Bonneville data from 1938 through 1942 are depicted in Figure 3-2. Note that temperatures exceeded the Washington criterion of 20 °C and reached as high as 22 °C.

Figure 3-2. Water Temperature at the Scroll Case of Bonneville Dam 1938-1942.

The extensive data base assembled by McKenzie and Laenen (1998) is difficult to use for analyzing and comparing temperature from site to site, because there is little consistency in station location or monitoring methods. Few of the sites have quality assurance objectives or followed quality control plans. Results can differ depending on the location of the sampling site. For example Figure 3-3 compares temperature data collected at Ice Harbor Dam on the Snake River from the scroll case and from stations in the fore bay and tail race in 1994. Note the differences in temperature at these stations throughout the monitoring period. These stations were not chosen at random. They were selected to specifically illustrate the point, but this kind of discrepancy is not rare in the assembled data and must be an important consideration in using this data for analysis or model development. In using these data it is important to compare like stations along the river (eg scroll case to scroll case, fore bay to fore bay) and to use long records or repetitive examples when drawing general conclusions about temperature trends.

Figure 3-3. Comparison of Daily Water Temperature measured at the Forebay, Scroll Case and Tail Race at Ice Harbor Dam in 1994.

3.3.2 Water Quality Criteria Evaluation

A visual scan of the available data shows that the rivers get quite warm, exceeding water quality criteria all along their lengths in the summer. This is confirmed by the data that Mackenzie and Laenen (1998) collected from total dissolved gas monitoring stations at the dams. Table 3-4 shows the frequency and magnitude of water quality criteria exceedances at nine dams along the rivers. Frequency ranged from 0.1 at Wells Dam on the Mid-Columbia to 0.18 at Priest Rapids on the Mid-Columbia and Ice Harbor and Lower Monumental on the Snake. The average magnitude of exceedance ranged from less than a degree C at Wells Dam to almost 2.5 °C at Little Goose on the Snake River.

Table 3-4. Frequency and average magnitude with which observed temperatures exceedOregon's and Washington's water quality criterion at selected locations on the Columbiaand Snake rivers. Observed temperatures are from the total dissolved gas monitoringprogram (McKenzie and Laenen, 1998)

Location	Exceeds Water Quality Criterion		Record Length
	Frequency	Magnitude	
Lower Granite Dam	0.15	2.04	5/30/88-9/17/96
Little Goose Dam	0.15	2.49	5/30/88-9/16/96

Lower Monumental Dam	0.18	2.10	5/29/88-9/17/96
Ice Harbor Dam	0.18	2.35	5/29/88-9/23/96
Wells Dam	0.10	0.87	4/18/93-9/2/97
Priest Rapids Dam	0.18	1.61	4/28/88-12/31/97
McNary Dam	0.17	1.65	4/2/85-12/31/97
John Day Dam	0.15	1.65	4/17/84-9/16/97
Bonneville Dam	0.14	1.39	4/3/86-11/2/97

Figure 3-4 and 3-5 portray the number of days that Washington, Oregon and Colville water quality criteria were exceeded all along the Columbia River in 1997 and 2000. The data for these figures was taken from McKenzie and Laenen, 1998 and the University of Washington DART Internet site. Figure 3-6 illustrates the water temperature along the Columbia River on August 8, 1995, August 16, 1996, and August 23, 1997. The white line represents water quality criteria. Washington and Colville criteria over lap in the upper river. Washington's criteria changes from 18 °C to 16 °C at river mile 590 and the Colville's criteria changes from 18 °C to 16 °C at river mile 545. Washington and Oregon criteria are both 20 °C in the lower river. Oregon's criteria applies on the lower river from river mile 303 to the mouth. Figure 3-7 shows the water temperature along the Columbia River on August 9, 2000. From these figures, based on existing data, it is clear that the entire Columbia River frequently exceeds water quality criteria.

Figure 3-4. July Through October, 1997 - Number of Days during which Water Temperature in the Columbia River Exceeded Water Quality Criteria in Washington, the Colville Reservation and Oregon and the Number of Days for which there are Data. The Oregon criteria apply from river mile 303 to the mouth.

Figure 3-5. July Through October, 2000 - Number of Days during which Water Temperature in the Columbia River Exceeded Water Quality Criteria in Washington, the Colville reservation and Oregon and the Number of Days for which there are Data. The Oregon criteria apply from river mile 303 to the mouth.

Figure 3-6. Water Temperatures along the Columbia River on August 8, 1995, August 16, 1996 and August 23, 1997 Compared to Washington, Colville and Oregon Water Quality Criteria. The Sampling Sites are the International Boundary, the Fore Bays of all the Dams and Beaverton, OR. The Oregon criteria apply from river mile 303 to the mouth.

Figure 3-7. Water Temperature in the Columbia River on August 9, 2000 Compared to Washington, Colville and Oregon Water Quality Criteria. Sampling Sites are the Fore Bays and Tail Races of the Dams. The Oregon criteria apply from river mile 303 to the mouth.

Figures 3-8, 3-9 and 3-10 show the number of days that Idaho, Oregon and WA water quality criteria are exceeded along the Snake River. These figures use the Idaho maximum criterion of 22 °C. That criterion is exceeded less frequently than the Oregon and Washington criteria for the same river

reaches.

Figure 3-8. July through October, 1993 - Number of Days during which Water Temperature Exceeded Idaho, Oregon or Washington water Quality Criteria in the Snake River and the Number of Days for which there are Data.

Figure 3-9. July Through October 1995 - Number of Days during which Water Temperature Exceeded Idaho, Oregon or Washington Water Quality Criteria in the Snake River and the Number of Days for which there are Data

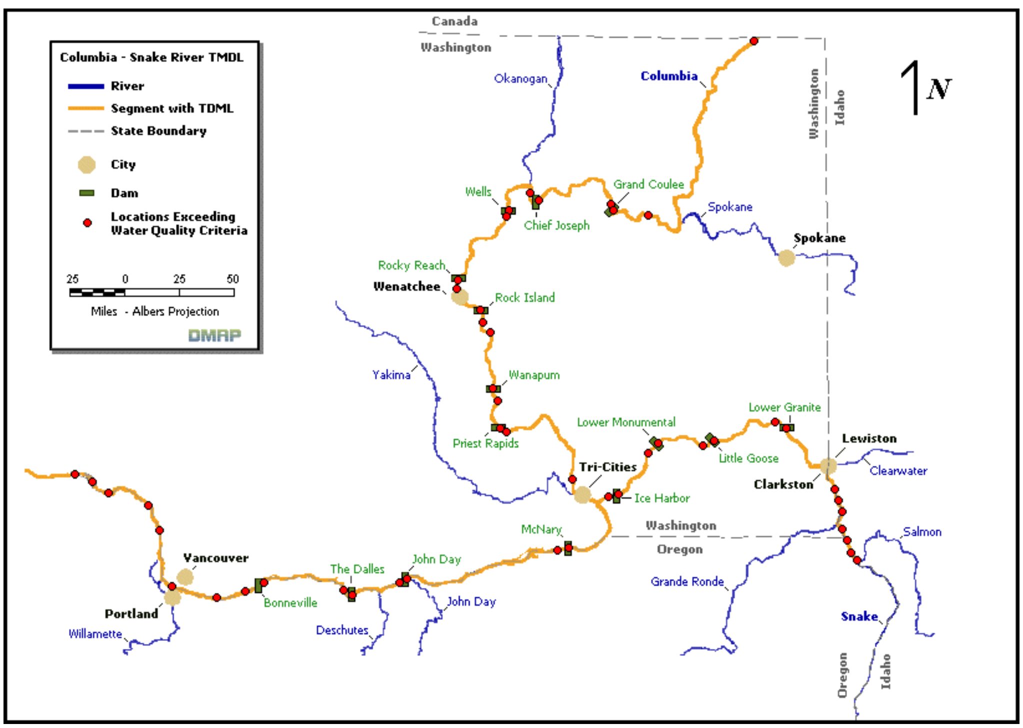
Figure 3-10. July Through October, 2000 - Number of days during which Water Temperature Exceeded Washington water Quality Criteria in the Snake River and the Number of Days for which there are Data.

Table 3-5 summarizes Idaho water quality criteria exceedances for the entire data set for the Idaho stations. This data was all taken from McKenzie and Laenen, 1998.

Table 3-5: Exceedances of Idaho's Maximum Criterion for water Temperature along the Snake River.

Location	Sampling Begun	Sampling Ended	Exceedances of 22 °C
Chalk Creek RM 188.2	7-12-91	4-2-96	22
River Mile 180	8-8-91	10-15-96	9
Cochrane Is. RM 178.2	7-11-91	9-4-95	44
River Mile 169.7	7-11-91	8-4-96	41
Billy Creek RM 164.6	9-27-91	12-31-95	46
Anatone, WA RM 167.2	10-1-59	9-30-93	798
River Mile 155.9	7-11-91	4-26-96	4

Figure 3-11 shows the locations of all the stations along the Columbia and Snake rivers that were sampled in the 1990s or later and have exceedances of water quality criteria. The figure includes the stations from McKenzie and Laenen, Washington's 303(d) list and the University of Washington, DART Internet



site.

Figure 3-11. Sampling sites along the Columbia River that exceeded Water Quality Criteria for Temperature in the 1990s or later.

The existing Columbia and Snake River systems exceed the water quality criteria for temperature frequently throughout their lengths. However, the water quality standards of Oregon and Washington and the Colville Tribe state that the criteria are not to be exceeded due to human or anthropogenic activities. We have already shown that the water quality criteria were exceeded at Rock Island Dam and Bonneville Dam when they were the only dams on the Columbia River (figures 3-1 and 3-2). Assuming that the water temperatures at those dams when they were the only dams on the river are indicative of the temperatures with relatively few impacts from human activities (closer to the site potential temperatures) we can compare that temperature record to the existing river temperatures to see if the temperature regime has been altered.

3.3.3 Changes in the Temperature Regime at Bonneville Dam

Bonneville Dam is the dam furthest downstream and is most likely to demonstrate any cumulative impacts on water temperature from the dams and other human activities upstream. Figure 3-12 provides information on the number of days that exceeded water quality criteria at Bonneville Dam. It compares two time periods: the eighteen years when Bonneville was the only dam on the river for 300 miles with the first eighteen years following construction of the last dam on the Columbia/Snake River System. The figure demonstrates a considerable increase in the number of days per year that criteria are exceeded. The mean number of days exceeding the criteria is four times greater (48.4 days versus 12.3 days) for the time frame after all the dams were constructed. Figure 3-13 shows the same information in a different way. The frequency of exceedance of the criteria was about 3% of the time during the period when Bonneville was the only dam for 300 miles and 13% of the time after all the dams were constructed.

Figure 3-12. Number of Days that exceeded 20 °C at Bonneville: Comparison of the two periods 1939-1956 and 1976-1993.

Figure 3-13. Frequency of Exceedance of 20 °C at Bonneville Dam for the two periods 1939-1956 and 1976-1993.

Figures 3-12 and 3-13 show that a difference exists in the number of days exceeding water quality criteria between the two time periods 1939-1956 and 1976-1993 but they do not explain the cause of the difference. It may be due to the presence of the dams and human activity or it may be due to other physical differences during the two time periods. The most obvious physical characteristics that govern water temperature are air temperature and flow in the river. Davidson (1964) reported that weather and river flow accounted for 81% to 85% of the variability in water temperature in the free flowing Columbia River at Rock Island Dam.

Figures 3-14 and 3-15 compare air temperature and flow for the two time periods. Figure 3-14 portrays the annual average of the maximum daily air temperatures at Goldendale, WA for the two time periods. The summary statistics for these data for the two time periods are:

	1939-1956	1976-1993
Maximum	65.08 F	63.09 F
Minimum	57.67 F	57.84 F
Mean	61.20 F	60.69 F

Figure 3-14. Annual Average of the Maximum Daily Air Temperatures at Goldendale, WA for the Two Periods 1939-1956 and 1976-1993

From visual examination and the summary statistics, the average annual air temperatures from the two periods do not appear to differ substantially. A two-tailed Student's T Test supports this. The probability that rejecting the null hypothesis would be wrong, as calculated by the T-Test, is 40%. Typically, for two sets of data to be considered different the probability is 10% or less.

The annual average of the daily average Columbia River flows at Grand Coulee for the two time periods are shown in figure 3-15. The summary statistics for these data for the two time periods are:

	1939-1956	1976-1993
Maximum	136298.4 CFS	132641.5 CFS
Minimum	71147.5 CFS	80343.0 CFS
Mean	110150.8 CFS	102136.3 CFS

Figure 3-15.
Annual Average of
the Daily Average
Flows at Grand Coulee for the Two Periods 1939-1956 and 1976-1993.

From visual inspection and the summary statistics there does appear to be somewhat more difference for flow than for air temperature. The probability that rejecting the null hypothesis would be wrong, as calculated by the T-Test, is 20%.

Neither air temperature nor river flow are significantly different between the two time periods and do not appear to account for the large increase in the number of days in which water temperature exceeded 20 °C. Davidson (1961) predicted that the dams on the Upper Columbia would increase the temperature of the river. During hot, dry summers he expected that the river temperature would increase as much as 5 °F in July and August and 1.5 °F in September between Chief Joseph Dam and Priest Rapids Dam.

In order to better understand the influence of air temperature and river flow on the number of days that water quality criteria are exceeded at Bonneville Dam in the two time periods 1939-1956 and 1976 to 1993, the number of days in which air temperature exceeded 90 °F and 80 °F and the number of days that river flow was less than 50,000 CFS and 40,000 CFS were computed. Table 3-6 shows the results of this analysis.

Table 3-6. Comparison of the number of days per year that water temperature exceeded 20 °C, Air Temperature exceeded 90 °F and 80 °F and Columbia River Flow was less than 50,000 CFS and 40,000 CFS for the two Time Periods 1939-1956 and 1976-1993.

	# Days water temp > 20 °C		**# Days Air Temp > 90 °F**		**# Days Air Temp > 80 °F**		**# Days River Flow < 50000 CFS**		**# Days River Flow < 40000 CFS**	
	1939-1956	1976-1993	1939-1956	1976-1993	1939-1956	1976-1993	1939-1956	1976-1993	1939-1956	1976-1993
Max	41	70	31	33	89	83	211	54	103	22
Min	0	3	3	0	41	49	5	0	0	0
Mean	12.3	48.4	17.7	18.44	64.3	63.8	86.17	13.5	35.28	3.72
St Dev	10.96	16.04	8.11	9.42	13.51	9.95	67.84	15.94	41.7	5.75
Varianc	120.23	257.43	65.86	88.7	182.47	99.04	4601.9	193.9	1738.7	33.03

Note that there is very little difference in the number of hot days per year in the two periods, the difference in the average number of days over 90 °F and 80 °F both being less than one day. There was a considerable difference in the number of low flow days/year during the two periods with the second time period averaging almost 73 fewer days with less than 50,000 CFS and almost 32 fewer days with less than 40,000 CFS. This indicates that differences in air temperature and river flow do not account for the differences in number of days during which water temperature exceeds 20 °C. Figures 3-16 and 3-17 show the number of days that water quality criteria are exceeded at Bonneville Dam in the two time periods 1939-1956 and 1976 to 1993, the number of days in which air temperature exceeded 90 °F and the number of days that river flow was less than 40,000 CFS. Only 90 °F and 40,000 CFS were graphed to minimize confusion in the graphs.

1939-1956 **1976-1993**

Figure 3-16: Comparison of the Number of Days Per Year that Water Temperature Exceeded 20 °C and Air Temperature Exceeded 90 °F for the Two Time Periods 1939-1956 and

1976-1993

Figure 3-16 shows that there is some degree of correlation between days exceeding water temperature of 20 °C with days exceeding air temperature of 90 °F in both time periods, but for the second time period, after the dams were constructed, the relationship exists at a much greater number of days over the criterion. The correlation coefficients are 0.68 for 1939-1956 and 0.45 for 1976-1993. Something other than air temperature is a significant factor in the difference between the number of days/year that exceed 20 °C during the two time periods.

1939-1956 **1976-1993**

Figure 3-17: Comparison of the Number of Days Per Year that Water Temperature Exceeded 20 °C and River Flow was less than 40,000 CFS for the Two Time Periods 1939-1956 and 1976-1993

Figure 3-17 shows that water temperature and river flow interact similarly to water temperature and air temperature. In the first time period before the dams were built there was a relationship between the number of days exceeding 20 °C and the number of low flow days with a correlation coefficient of 0.45. In the second period there was no defined relationship, the correlation coefficient being 0.02.

Table 3-7 lists the correlation coefficients for all four tests: number of days with water temperature over 20 °C tested against number of days with 1) air temperature over 90 °F, 2) air temperature over 80 °C, 3) river flow less than 50,000 CFS and 4) river flow less than 40,000 CFS. Table 3-8 lists the multiple regression statistics for the same 4 tests. Note that before the dams were constructed the strongest correlation was with test # 1, days over 90 °C air temperature. But after the dams were constructed, test #2, days over 80 °F air temperature, became more important. Both of the flow tests had smaller correlation coefficients after the dams were built. Similarly, table 3-8 shows that before the dams were built, test #1, number of days with air temperature over 90 °F accounted for most of the days over 20 °C water temperature. The regression coefficient was 0.929 and the P value was 0.039. After the dams were constructed, test #2, days over 80 °F air temperature had the highest regression coefficient, 0.627 and accounted for more days over 20 °C water temperature than test #1.

This illustrates an effect of the dams on water temperature. The dams make phenomena that occur over longer time scales more important in determining water temperature. Hence 80 ° days, which occur over a longer time scale than 90 ° days become a more important factor in the regression equation. This occurs because the impounded river moves more slowly and is of greater volume than the free flowing river.

Table 3-7: Correlation coefficients for four tests: water temperature over 20 °C tested against number of days with 1) air temperature over 90 °F, 2) air temperature over 80 °C, 3) river flow less than 50,000 CFS and 4) river flow less than 40,000 CFS

	Air > 90 °F	**Air > 80 °F**	**Flow < 50K CFS**	**Flow < 40 K CFS**
1939 - 1956	.681	.509	.256	.310
1976 - 1993	.450	.535	.026	.028

Table 3-8: Multiple Regression Statistics for four tests: water temperature over 20 °C tested against number of days with 1) air temperature over 90 °F, 2) air temperature over 80 °C, 3) river flow less than 50,000 CFS and 4) river flow less than 40,000 CFS. The Multiple R squared for the regressions were 0.487 for 1939-1956 and 0.328 for 1975-1993.

	Air > 90 °F		**Air > 80 °F**		**Flow < 50K CFS**		**Flow <40 KCFS**	
	Coefficient	**P Value**	**Coefficient**	**P Value**	**Coefficient**	**P Value**	**Coefficient**	**P Value**
1939 - 1956	.929	.039	.114	.726	.036	.549	.002	.980
1976 - 1993	.448	.413	.627	,205	.399	.581	-0.76	.656

Clearly some factors other than air temperature and river flow are contributing to the increased number of days during which water quality criteria are exceeded after the dams were built. There are other meteorological factors in addition to air temperature that have a role in water temperature. Wind speed, cloud cover and snow pack are probably important. The data are unavailable to evaluate all of these parameters, but air temperature and river flow provide a good estimation of the relation between meteorology and water temperature. Air temperature reflects cloud cover and solar radiation, and river flow reflects snow pack and precipitation.

The data showing that the number of days during which water temperature exceeded the water quality criteria increased 4 times after all the existing dams were built is a strong line of evidence that the dams have resulted in significant changes to the thermal regime of the Columbia River.

3.3.4 Temperature at Rock Island Dam

Figure 3-18 provides information on the number of days that exceed water quality criteria at Rock Island Dam. It demonstrates that the frequency of exceedance of the water quality criterion was higher for the period 1933-1941 (0.133) when Rock Island was the only Dam on the mid-Columbia than for the first nine years after all the dams had been constructed, 1976-1985 (0.104). This relationship is just the opposite of the relationship at Bonneville. Figure 3-19 displays the number of days exceeding the criteria at Rock Island Dam for the entire record.

Figure 3-18. Frequency of Exceedance of 18 °C at Rock Island Dam 1933-1941 and 1977-1984

Figure 3-19. Numbers of days in which the Scroll Case Water Temperature at Rock Island Dam Exceeded 18 °C: 1933-1985, 1989,1990,1991,1996.

There appears to be warmer years and cooler years but there does not appear to be a relationship in which the exceedance increased after construction of all of the dams as was the case at Bonneville. Davidson (1961) predicted an increase in temperature between Chief Joseph Dam and Rock Island Dam of 2 °F in July, 3 °F in August and 1 °C in September. Such an increase would not be expected to increase the number of days that criteria are exceeded as significantly as at Bonneville, if at all some years. In fact it was suggested at a public workshop that the temperature at Rock Island Dam could be used as a line of evidence regarding whether the temperature shift at Bonneville Dam is indeed due to dams and other activity in the water shed or is instead due to global warming. It was suggested that if Rock Island shows the same temperature pattern as Bonneville, climate change might be the explanation for the increase in number of days of exceedance. In fact the Rock Island data does not show the same patterns as the Bonneville data.

3.3.5 Comparison to the Frazer River

The possible effect of climate change on the Columbia River temperature regime can be further evaluated by examining water temperature in the Frazer River. The Frazer River is a large northern temperate zone river like the Columbia. It Drains 230,000 square kilometers (89,700 square miles) and is 1370 km long (849 mile). Average daily discharge at Hope, B.C. peaks at about 7000 cubic meters per second (247,249 cfs). Natural water temperature of the Frazier and Columbia Rivers would be expected to behave similarly in response to climate. If climate change is responsible for warming the temperature regime in the Columbia River, similar trends would be expected in the Frazer. Foreman et al (2001) conducted a retrospective analysis of flows and temperatures of the Frazer River. They found that average summer temperature at Hell's gate east of Vancouver increased 0.012 °C per year from 1941 to 1998. This trend is not significantly different from zero at the 95% confidence level. From 1953 to 1998 they found the trend to be 0.022 °C per year. This is significant at the 98% confidence level. Foreman et al (2001) attribute most of the river warming to climatic effects. At Bonneville using the same data depicted in figures 3-12 and 3-13 the average temperature from July 1 to September 15 was 18.8 °C for the period from 1938-1956 and 20.5 °C for the period from 1976 to 1993. This difference of 1.7 °C cannot be explained by the 0.02 °C per year trend observed in the Frazer River. Nevertheless, global warming is likely small factor leading to the warming temperature regime of these rivers.

3.3.6 Temperature Gradients in the Reservoirs

Another assembly of temperature data was compiled by Karr et al (1998) for the Lower Snake River. They included data from 16 transects spaced along the river from just above the Clearwater River to just below the confluence of the Snake and Columbia Rivers. Karr et al also reported data collected from the fish ladders of the four lower Snake River Dams.

The transects were monitored in 1991 and 1992. Temperature measurements were taken at four depths and 3 specific locations across the river: near the surface, 1/3 depth, 2/3 depth and near the bottom at mid-channel, and 1/4 of the width from each bank. Table 3-9 was constructed from temperature contour figures presented in Karr et al (1998).

Table 3-9: Temperature measurements from the surface and bottom of the lower Snake River reservoirs near each dam. The data was constructed from figures in Karr et al (1998).

	Lower Granite		**Little Goose**		**Lower Monumental**		**Ice Harbor**	
Date	**Surface**	**Bottom**	**Surface**	**Bottom**	**Surface**	**Bottom**	**Surface**	**Bottom**
08/08/91	22.2 C	21.1 C	23.8 C	21.1 C	23.3 C	20.5 C	25.5 C	21.1 C
08/23/91	22.2 C	17.7 C	22.7 C	22.2 C	22.7 C	21.6 C	23.3 C	22.2 C
08/27/91	21.1 C	17.7 C	21.6 C	19.4 C	21.6 C	21.6 C	21.6 C	21.6 C

This table illustrates water conditions near the dams before and after the release of cold water from Dworshack Dam on the Clearwater River just upstream of the Snake River. It shows the warm temperatures that can develop behind the dams, the temperature gradients that can develop with depth and the effects of the cold water releases on water temperature in the Snake River. On August 8, 1991, the water temperature exceeded the water quality criterion of 20 C throughout the water column near all of the dams. Further there was a temperature gradient between the surface and the bottom in the reservoirs ranging from 1 C near Lower Granite Dam to 4 C near Ice Harbor Dam. On August 16, 1991, the Corps of Engineers modified release of water from Dworshack Dam on the Clearwater River, to provide cool water to the Snake River. They released water at a temperature of 7.2 C at a flow rate of 10,000 cubic feet per second (CFS) from August 16, 1991 to August 22, 1991 (Karr et al, 1998). By August 23, 1991 the water released from Dworshack had cooled the deeper water near Lower Granite, creating a temperature gradient of over 4 C between the surface and bottom. It also appears to have had a cooling effect downstream, reducing the temperature gradients near the dams to no more than 1 C. The temperature still exceeded the water quality criterion near all the dams except Lower Granite. On August 27, 1991, the lower river had cooled more but the criteria were still exceeded in most places near the dams. Some of the transects not shown here exhibited greater cooling. Transect number 6 in the reservoir behind Little Goose Dam was below the criteria throughout its depth and transect number 7 also in the reservoir behind Little Goose Dam was below the criterion for most of its depth.

3.3.7 Temperature in the Fish Ladders

Karr et al (1998) also presented temperature data from the fish ladders at the Snake River Dams. Table 3-10, constructed from Karr (1998) data, displays the mean monthly temperatures in the fish ladders from 1991 through 1994. The temperature data was reported by Karr as °F and converted here to °C. The tail race station is outside of the fish ladder below the dam. The fish ladder temperature, like the tail race temperature varied considerably from year to year with 1991 and 1992 being warm years and 1993 and 1994 being cooler years. While the lower fish ladder temperatures were higher than the tail race temperatures in all but one of the cases where both data existed, the temperature difference between the two varied widely. In the one case when the tail race was warmer it was 1.8 °C warmer. The rest of the time the lower fish ladder varied from 0.1 °C warmer to 2.6 °C warmer.

In summary, there is an extensive data base for water temperature along the Columbia and Snake Rivers. We know from the data that the rivers are quite warm in the summer, with records that exceed the ID, OR and WA water quality criteria at times along their length. The earliest records from Rock Island Dam in 1933 and Bonneville Dam in 1938 include exceedances of the water quality criteria. In 1933 Rock Island was the only dam in the Columbia River. In 1938 Rock Island and Bonneville were the only two dams on the rivers. Data from Bonneville Dam indicates that the number of days with water temperatures over the state water quality criteria have increased significantly since the system of dams was constructed on the two rivers. The increased number of days that water quality criteria are exceeded after the dams were built is not explained by differences in air temperature or river flow. Data from Rock Island Dam does not show the same relationship. In fact, there does not appear to be any relationship at Rock Island Dam between the number of days each year that criteria are exceeded and construction of the system of dams on the rivers. The existing data record shows temperature gradients with depth in the reservoirs in the lower

Snake River and it shows effects of cooling water from the Clearwater on the temperature gradients and the over all temperature of the lower Snake. Finally there is some temperature data from fish ladders at dams on the Lower Snake which shows that the ladders can get warm, at times warmer than the tail race temperature at the dams.

Table 3-10: Mean Monthly temperatures of fish ladders at the four lower Snake River Dams from 1991 through 1994. This figure is taken from Karr et al (1998). The temperature was reported by Karr in °F and converted here to °C.

		1991			1992			1993			1994		
Dam	Month	Tailrace	Lower	Upper	Tailrace	Lower	Upper	Tailrace	Lower	Upper	Tailrace	Lower	Upper
Ice	Aug	22.4	23.9		20.8	22.0	22..1	19.4	19.8	20.1	19.5	20.4	20.6
Harbor	Sep	20.3	22.3	20.1	19.7	20.9	19.8	19.1	19.8	19.8	20.0	20.4	20.2
	Oct	16.1	18.7	17.6	15.7	16.0	15.9				17.2	17.3	17.2
Lower	Aug	22.4		22.7	20.7	21.7	21.9	19.1	19.7	20.2	18.4	19.8	19.8
Monu	Sep	20.8		20.6	21.2	19.4	19.8	19.4	19.7	20.0	20.1	20.5	20.6
Mental	Oct	15.7		15.9		15.5	15.7					14.7	17.1
Little	Aug		22.6	22.8	21.1	22.2	22.3	19.1	20.0	20.0	18.5	19.5	19.8
Goose	Sep	19.3	20.1	20.2	18.9	19.2	19.1	20.1	20.6	20.5	20.6	20.8	21.0
	Oct	15.7	18.0	15.9	15.3	15.7	15.5				16.8	17.1	17.2
Lower	Aug	21.1	23.5	23.9	21.7	23.1	23.2	19.2	20.3	20.5	19.8	21.9	21.5
Granite	Sep	18.9	19.2	19.7	17.1	18.8	18.6	19.0	20.6	21.0	20.2	20.7	20.1
	Oct	15.9	18.1	16.8	15.3	15.8	15.8				16.3	16.4	16.6

3.4 Temperature Modeling

3.4.1 Introduction to the Model

EPA has developed a mathematical model to simulate temperature in the Columbia and Snake Rivers. This model, called RBM-10, is described in the report, "Application of a 1-D Heat Budget Model to the Columbia River System" (EPA, 2001). RBM-10 is a one-dimensional mathematical model of the thermal energy budget that simulates daily or hourly average water temperature under conditions of gradually varied flow. Models of this type have been used to assess water temperature in the Columbia River system for a number of important environmental analyses. The Federal Water Pollution Control Administration (Yearsley, 1969) developed and applied a one-dimensional thermal energy budget model to the Columbia River as part of the Columbia River Thermal Effects Study. The Bonneville Power Administration et al. (1994) used HEC-5Q, a one-dimensional water quality model, to provide the temperature assessment for the System Operation Review, and Normandeau Associates (1999) used a one-dimensional model to assess water quality conditions in the Lower Snake River for the U.S. Army Corps of Engineers.

RBM-10 uses real time meteorological and hydrological information to simulate water temperature in the river. In this case, 30 years of meteorological and hydrological data from 1970 to 1999 was used to simulate both the actual water temperatures for those years and the temperatures that would have occurred in the absence of human activity. The simulations of existing conditions were compared to the temperatures recorded at the Total Dissolved Gas monitoring stations in the tail races of the dams in order to evaluate the performance of the model.

The ability of RBM-10 to simulate average temperature is shown in Appendix D of the modeling report (EPA, 2001). Figure 3-20 is an example of graphs in the report that compare actual data with the model simulations. This one compares simulated and observed temperatures from John Day Dam. Visually, the simulated and observed values appear to track each other quite closely. Tables 3-11 and 3-12 illustrate the results of a statistical analysis comparing the simulated and observed temperatures.

Figure 3-20. Simulated and Observed Water Temperature at Bonneville Dam 1990-1994.

Table 3-11. Mean and standard deviation of the difference between observed and simulated temperatures at John Day Dam (Columbia River Mile 215.6) for the period 1990-1994. Observed data are from the total dissolved gas monitoring locations in the forebay of the dam at a depth of 15 feet. Dashes (---) indicate limited (N<10) data for computing statistics

Time Period	Mean Difference	Standard Deviation of Difference
January-February	0.580	1.309
March-April	1.273	0.730
May-June	0.283	0.924
July-August	0.288	0.986
September-October	0.9425	0.646
November-December	---	---
Entire Year	0.560	1.021

Table 3-12. Slope of line and R^2 for regression of observed temperature data on simulated results in the Columbia and Snake rivers for the period 1990-1994. Regression was constrained to force the straight line to pass through the origin (X (simulated)=0, Y (observed)=0).

Measurement Site	Slope of Line	R^2
Wells Dam	0.995	0.973
Priest Rapids Dam	0.999	0.940
McNary Dam	1.004	0.929
John Day Dam	0.995	0.976
Bonnevile Dam	0.995	0.904
Lower Granite Dam	1.005	0.931
Little Goose Dam	0.997	0.907
Lower Monumental Dam	0.992	0.923
Ice Harbor Dam	0.998	0.929

The comparison of simulated and observed temperatures gives us an estimation of the accuracy of the model in simulating existing river conditions. It is not possible to develop a similar estimate for simulations of temperature in the absence of human activity because there are no observed values available for a comparison. Unless there are significant differences in the sources and sinks of heat between the existing river and the river without human activity, one would expect the model to accurately simulate either condition. There are at least two differences that might make the simulations different that need to be evaluated: unregulated flow and hyporheic flow.

Flow in the river now is regulated by storage reservoirs to prevent flooding and provide water for irrigation, power generation and navigation. The result is that flows generally do not get as low in the summer as they did before human development and they generally do not flood as much as they did before. The model simulations for both existing conditions and conditions without human development use regulated flows. They are regulated by reservoirs and other human activities upstream of this TMDL project area. The result of this is that the summer low flows in the model may not be as low as they would be without flow regulation. The river under lower flows would probably tend to heat up faster in the early summer and get warmer. However, the lower flows would also make the river cool faster in the late summer and fall. So the effects of regulated flows on the modeling result would be to under-estimate the river temperature in the absence of human activity and underestimate how long the river stays warm in the fall in the absence of human activity than it would have.

Another change in the rivers since human development is the loss of hyporheic flow exchange. Before the rivers were dammed they had considerable alluvial flood plains as discussed in section 3.0. These flood plains absorbed flow into the gravelly hyporheic zone during high flows and released it to the river during lower flows. Now those flood plains are flooded year around and no longer exchange flows with the river. The model does not account for these flows under either the existing scenario or the no human activity scenario. Since these hyporheic flows tended to be sources of cool water during low flow periods, the model would tend to overestimate the temperature in these areas. Since the magnitude of the hyporheic flows is unknown, it is difficult to assess their effect on the overall temperature of the river. The Columbia is a very large river, and it would require considerable flow to noticeably affect the cross sectional average temperature of the river. However, even if they did not lower the overall cross sectional temperature, the hyporheic flows would have provided local cooling. These areas of localized cooling spaced along the river probably served as refuges for salmon.

3.4.2 Differences in the Temperature Regime with the Dams in Place

The model was run using 30 years of actual meteorological and hydrological data for both the existing conditions and conditions in the absence of human activity in the project area (dams taken out for the simulations). The hourly cross-sectional average temperature can be plotted against time for any location along the river. Figure 3-21 is an example of temperature with and without dams in place for 1990 at Ice Harbor Dam.

Figure 3-21. Simulated water Temperature at Ice Harbor Dam 1990 - Dams In Place and Dams Removed

This figure illustrates 3 differences in the temperature regimes of the river with and without dams in place.

- The impounded river generally warms more slowly than the river would without dams so that it is somewhat cooler in the spring.
- The existing river stays warm in the late summer longer than the river without dams. That is, it cools more slowly.
- The temperature in the impounded river does not fluctuate in the short term as much as the temperature in the free flowing river. Temperature in the free flowing river fluctuates more diurnally and in response to meteorological conditions.

Figures 3-12 and 3-13 had demonstrated that the existing river at Bonneville Dam had four times as many days per year in excess of 20 °C than the river had before all the dams were constructed. One reason for this may be the fact that the impounded river cools much more slowly in the fall and does not fluctuate in response to short term changes in meteorology. Figure 3-21 shows considerably greater diurnal and short term fluctuation in the free flowing river. Figure 3-22 illustrates the relationship of the short term fluctuations to meteorology. It is from the same data set as figure 3-20 but shows only the warm part of the year and includes the air temperature at Lewiston ID. Each of the rather dramatic short term decreases in water temperature in the free flowing river was accompanied by equally obvious decreases in the air temperature at Lewiston. The impounded river was relatively unaffected by these decreases in air

temperature.

Figure 3-22. Simulations of Water Temperature at Ice Harbor Dam 1990 with Dams in Place and Dams removed compared to Air Temperature at Lewiston, ID.

3.4.3 Relative Impacts of Dams and Tributaries on Temperature

The model was further used to compare the relative impacts of the dams and advected heat from tributaries on the water temperature of the rivers. The objectives of this comparison were to assess the relative contribution of impoundments and tributary inputs to changes in the thermal regime of the Columbia and Snake rivers. To capture the environmental variability in hydrology and meteorology, the 21-year record of stream flows and weather data from 1975 to 1995 was used to characterize river hydraulics and surface heat transfer rates. The period from 1975 to 1995 was chosen to represent a period of relatively consistent management of the hydroelectric system. This assumption was based on the fact that it includes the period for which all the dams that are presently installed have been in operation. However, the assumption is confounded to a degree by the change in operation of Dworshak Dam beginning in the summer of 1992. Selective withdrawal of cold water at Dworshak Dam, beginning in 1992, has led to modifications in the temperature regime of the Snake River (Karr et al., 1998). For the period 1992-1995, measured temperatures at Dworshak Dam and at Orofino, Idaho, were used to account for the effects of selective withdrawal at Dworshak Dam.

The assessment of impacts to the thermal regime of the Columbia and Snake River was based on the following three scenarios:

Scenario 1 This scenario includes the existing configuration of dams, hydrology, and meteorology from 1975 to 1995.

Scenario 2 This scenario assumes the Columbia River downstream from Grand Coulee and the Snake River downstream from Lewiston, Idaho, are unimpounded and that hydrology, meteorology, and tributary temperatures are the same as Scenario 1.

Scenario 3 This scenario assumes the existing configuration of dams, with hydrology and meteorology for the period 1975 to 1995. Tributary input temperatures are estimated from the 21-year meteorologic record using Equation 25, but are not allowed to exceed 16 °C (60.8 °F).

For each of these scenarios, daily average water temperatures were simulated and the mean, mean plus one standard deviation, and the mean minus one standard deviation of the simulated water temperatures were compared to 20 °C (68 °F). A single benchmark of 20 °C was used to simplify this assessment of relative impacts from dams and tributaries. It should be noted that this assessment is preliminary to the TMDL, which must address the varying water quality criteria that apply to each river reach.

The frequencies of temperature excursions above 20 °C for each scenario as a function of Columbia and Snake River Mile are shown in Figures 3-23 to 3-28. The error bars in each of the plots represent the frequencies estimated with the simulated means plus one standard deviation and the simulated means minus one standard deviation.

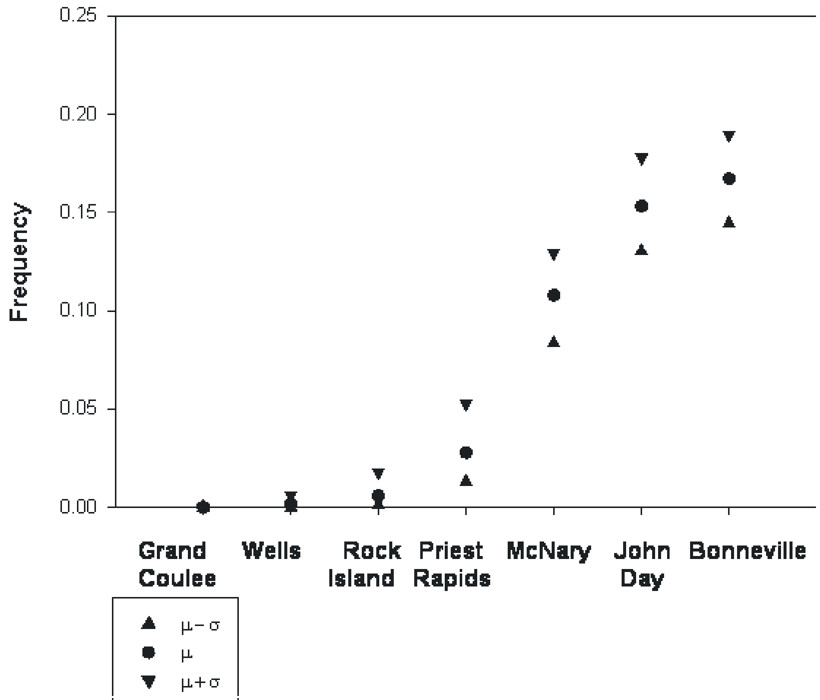


Figure 3-23. Frequency of predicted water temperature excursions in the Columbia River withdams in place.

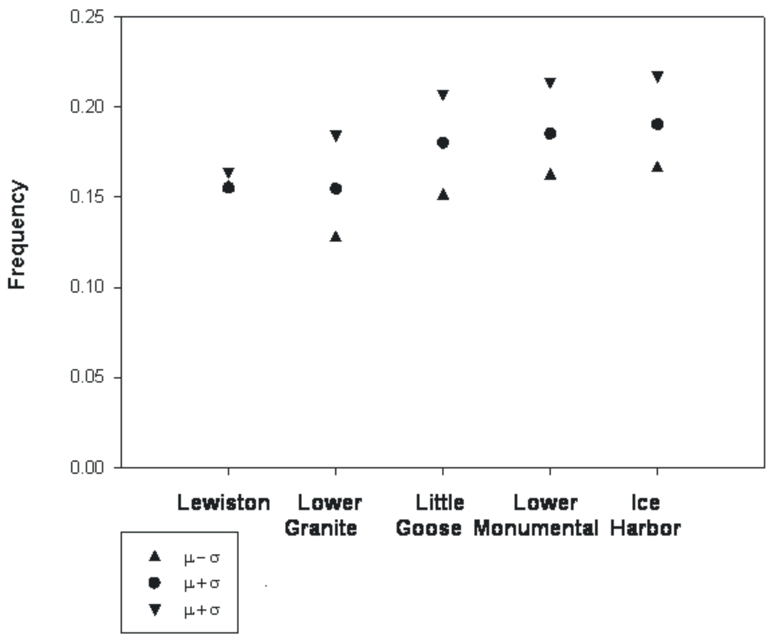


Figure 3-24. Frequency of predicted water temperature excursions in the Snake River with dams in place.

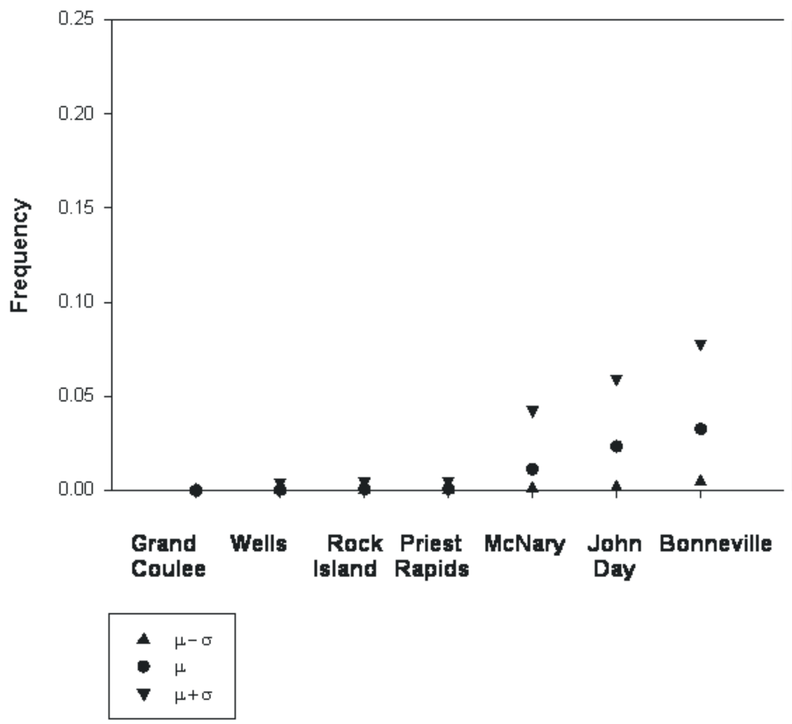


Figure 3-25. Frequency of predicted water temperature excursions in the Columbia River for the unimpounded river.

Figure 3-26. Frequency of predicted water temperature excursions in the Snake River for the unimpounded river.

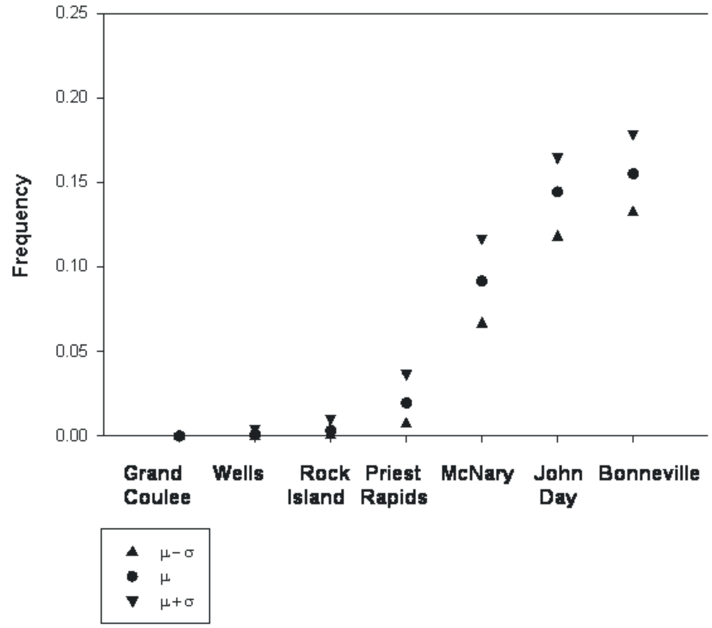


Figure 3-27. Frequency of predicted water temperature excursions in the Columbia River with dams in place and tributaries equal to or less than 16 _C.

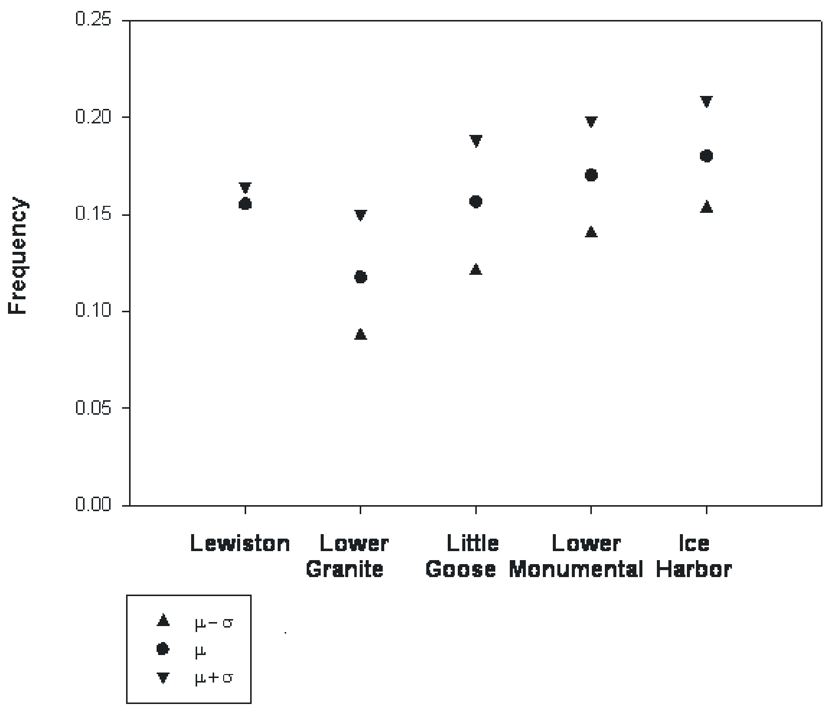


Figure 3-28. Frequency of predicted water temperature excursions in the Snake River with dams in place and tributaries equal to or less than 16 _C.

The frequency of temperature excursions, calculated from the model simulations, establish a basis for assessing the relative impact of dams and tributary inflow on the thermal regime of the Columbia and Snake rivers. The frequency of temperature excursions, calculated from the mean plus and minus one standard deviation of the model estimates, provide the basis for assessing the significance of differences between scenarios.

For the Columbia River in Scenario 1, the existing conditions with dams in place, the mean annual frequency of temperature excursions of 20 °C increases from near zero at Grand Coulee Dam to somewhat greater than 0.03 at Priest Rapids. The influence of the warmer Snake River leads to an increase of the average frequency of excursions between Priest Rapids and McNary Dam from 0.03 to 0.11. Downstream from McNary Dam, the mean frequency of temperature excursions continues to increase to 0.17 at Bonneville Dam. The range of the frequency of excursions for the simulated average plus one standard deviation and the simulated average minus one standard deviation is of the order of _0.03.

For the unimpounded case (Scenario 2), the mean annual frequency of excursions is approximately 0.03 at Bonneville Dam. The estimated uncertainty of the frequency increases slightly compared to the results of Scenario 1, so that the frequencies of temperature excursion associated with the mean simulation plus one standard deviation are approximately 0.04 greater than that of the simulation. The increase in the uncertainty of the estimate for the river in the unimpounded scenario is due to the change in system dynamics associated with shallower depths and higher velocities. In spite of the increase in uncertainty, the difference in Scenarios 1 and 2 at those sites downstream from the confluence of the Snake River are clearly outside the bands defined by one standard deviation of the state estimates. In a qualitative sense, these differences are significant; that is, the unimpounded Columbia River has significantly fewer temperature excursions than does the impounded river. It is worth noting that the simulated frequency of exceedance of 20 °C at Bonneville Dam (0.03) is the same as that developed from existing scroll case data reported in figure 3-13.

The frequency properties of Scenario 3, for which tributary temperatures are constrained to be always less than 16 °C, are similar to Scenario 1 on the Columbia River upstream of its confluence with the Snake. The combined average annual flows of advected sources in this segment (Table 2-1) are less than 10 percent of average annual flow of the Columbia River at Grand Coulee Dam. The impact of these sources on the thermal energy budget of the main stem Columbia is, therefore, small. The 16 °C constraint was not applied to the Snake River and the warming effect of the Snake River on the Columbia is evident in the increase in the frequency of excursions between Priest Rapids Dam and McNary Dam. The net result being that frequency of excursions is not significantly different between Scenarios 1 and 3.

In the Snake River, with dams in place (Figure 3-24), the mean frequency of temperature excursions is relatively high (0.15) at the starting point (Snake River Miles 168.0), drops slightly due to the influence of the Clearwater River, then increases to 0.19 between there and Ice Harbor Dam (Snake River Miles 9.0). Because the Snake is a smaller river, it responds more rapidly to changes in systems dynamics. This, in turn, leads to larger uncertainty in the estimates as reflected in increased ranges of both frequency and magnitude of excursions. For the unimpounded case (Figure 3-26), the analysis predicts that the mean frequency of temperature excursions at Ice Harbor is approximately the same as the initial point near Anatone, Washington. The Clearwater River has a noticeable impact on water temperatures of the Snake River as shown by the reduction in the mean frequencies of temperature excursions for Scenarios 2 and 3 at Lower Granite Dam compared to the initial conditions for the Snake River at Anatone, Washington.

The wider bands of uncertainty reduce the significance of the results for the Snake River scenarios in the estimated frequency and magnitude of temperature excursions. At Lower Granite Dam, the differences in the three scenarios are small and within the uncertainty bands defined by one standard deviation of the estimates. The qualitative level of significance in differences between Scenarios 1 and 2 increases downstream. At Ice Harbor Dam, the mean values of the frequency estimates for Scenario 2 are outside the uncertainty bands defined by one standard deviation of the state estimates of Scenario 1. Differences between Scenarios 1 and 3 are significant only at Lower Granite, where the impact of lower temperatures in the Clearwater River is still important.

Changes in cross-sectional daily average water temperature between initial conditions and some downstream point in rivers are due to (1) meteorology (wind speed, air temperature, cloud cover, air moisture content), (2) river depth, and (3) travel time between the two points. The meteorology determines the maximum temperature the water body can achieve; the depth and certain components of meteorology determine the rate at which the water body exchanges heat with the atmosphere; and the travel time determines the importance of initial conditions.

Some limits on the cross-sectional daily average water temperature in rivers can be estimated by defining the equilibrium temperature as the temperature a body of water would reach after very long exposure to a specific set of meteorological conditions. For a river moving with an infinitely high speed, the cross-sectional daily average water temperature at some downstream point will be exactly the same as the initial conditions. The meteorology would have no effect on cross-sectional daily average water temperature for this case. A water body at rest (no velocity) under constant meteorological conditions would eventually reach the equilibrium temperature determined by wind speed, air temperature, cloud cover, and air moisture content. The water depth and certain components of the meteorology would determine the time it takes to reach the equilibrium temperature.

The impact of structural changes on the cross-sectional daily average water temperature river system, such as the construction and operation of dams and reservoirs, is determined by the relative importance of the three factors described above. The results for Scenarios 1 and 2 imply that the structural changes associated with construction and operation of hydroelectric facilities on the Columbia and Snake rivers have led to changes in the travel times that are sufficient to modify the temperature regimes of these rivers.

The impact of advected sources such as tributaries and point discharges on the cross-sectional daily average water temperature of the main stem Columbia and Snake rivers is determined by the ratio of advected energy from the source to the advected energy of the main stem. Contribution of thermal energy of most of the advected sources (tributaries and point sources) is small due to the magnitude of their flow compared to the main stems. The Clearwater River does have a significant cooling effect on the cross-sectional daily average water temperature of the Snake River. In addition, the Snake River has a significant warming effect on the cross-sectional daily average water temperature of the Columbia River.

3.5 Synthesis of Temperature Information

In the hot, dry summer climate of the Columbia Plateau and the Snake Plain it is important to look at the entire temperature regime in order to understand how these rivers support cold water fish like salmon. Important features of the temperature regime of the river include the maximum temperatures reached, the daily temperature fluctuations, the speed with which the water cools in the fall, the areas of cool temperature (refugia) provided by the alluvial flood plains, etc. While the role that these play in salmon ecology may not be fully known, they are each undoubtedly woven into the salmon survival strategy.

A synthesis of the information discussed in this chapter on existing temperature data and temperature modeling provides information about the natural and existing temperature regimes of the river:

- The water temperatures of the rivers before construction of the dams could get quite warm, at times probably exceeding even the 20 °C temperature criteria of Oregon and Washington on the lower Columbia River.
- However, these warm excursions were much less frequent without the dams in place. Both temperature observations and modeling simulations show that the frequency of exceedance at Bonneville Dam of 20 °C increased from about 3% in the absence of dams to 13% or greater with the dams in place.
- The dams appear to be the major cause of warming of the temperature regimes of the rivers. Model simulations using the existing temperatures of tributaries and holding tributary temperatures to 16 °C revealed no differences in the frequency of excursion of 20 °C.
- Global warming or climate change may play a small role in warming the temperature regime of the Columbia River to date. The Frazer River, with no dams, shows an increasing trend in average summer time temperature of 0.012 °C/year since 1941, 0.022 °C/year since 1953. The average summer time temperature at Bonneville Dam on the Columbia River increased from 18.8 °C before all the dams were constructed to 20.5 °C after all the dams were constructed.
- The free flowing river water temperatures fluctuated diurnally more than the existing temperatures so while they would get quite warm in the day they would be cooler at night.
- The free flowing river water temperature fluctuated in response to meteorology more than the impounded river. Cooling weather patterns tended to cool the free flowing river but have little effect on the impounded river.
- The natural water temperatures cooled more quickly in the late summer and fall.
- Alluvial flood plains scattered along the rivers moderated water temperatures, at least locally, and provided cool water refugia along the length of the rivers.
- The existing river can experience temperature gradients in the reservoirs in which the shallow waters are warmer.
- Fish ladders, which provide the only route of passage for adult salmon around the dams, can become warmer than the surrounding river water.

The goal for ameliorating temperature problems in the Columbia and Snake River main stems should be to restore as many of these natural characteristics of the temperature regime as possible. The TMDL will establish the heat reductions that will allow the bulk or thalweg temperature of the existing river to match the annual temperature cycle of the natural river. Meeting these reductions will correct some problems in the existing temperature regime. Essentially the daily maximum temperatures will be more in line with natural daily maximums throughout the year, including the late summer and fall. However, this will not necessarily eliminate the problems in important salmon habitats like the fish ladders and the shallow areas in the reservoirs. It also won't necessarily restore the temporal fluctuations and the cold water refugia which provided cooling times and areas for salmon in the natural rivers.

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